The spatial and community-context of ecological specialisation

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DOI:
10.33612/diss.119803987

Nederlandse samenvatting

De ruimtelijke- en gemeenschapscontext van ecologische specialisatie

Onze wereld is ontzettend heterogeen; van open landschappen tot gesloten bossen, van laagland tot hoogland en van droge vlaktes tot moerassen. Soorten passen zich aan verschillende omstandigheden aan en vertoeven het best onder hun specifieke condities. Denk bijvoorbeeld aan bergduivels (Australische hagedissen) die water verzamelen met hun schubbige huid om de droogte te overleven of aan lama's die gemakkelijker zuurstof kunnen opnemen hoog in de bergen waar ze leven. Het is schitterend om deze aanpassingen te zien, maar toch is het nodig dat soorten ook wat flexibel zijn, aangezien de wereld zowel in tijd als in ruimte vrij dynamisch is. Een boom kan omvallen en een heel nieuwe leefruimte creëren, overvloedige regenval kan het landschap aanpassen, maar ook menselijke invloeden zoals ontbossing en eutrofiëring brengen grote veranderingen met zich mee.
Verschillende landen hebben vorige zomer hun hitterecords verbroken. Helaas is dit niet zomaar een eenmalig gegeven, maar een duidelijk signaal van klimaatverandering. De mens bouwt hiervoor onder andere airconditionings, maar kan zich ook gedragsmatig aanpassen of de veranderingen proberen te verdragen. Andere soorten gaan hetzelfde proberen te doen. Als ze dit niet kunnen, betekent dit voor hen het einde. Soorten kunnen zich daarnaast ook genetisch aanpassen aan veranderende omstandigheden al gebeurt dit doorgaans over meerdere generaties. Deze aanpassingen aan wijzigende condities is de rode draad doorheen mijn thesis. Vele soorten worden bedreigd door de klimaatverandering en we kunnen de klok helaas niet volledig terugdraaien. Wat we wel kunnen is proberen te achterhalen welke factoren adaptatie kunnen helpen. Begrijpen onder welke omstandigheden adaptatie waarschijnlijker is, kan helpen voor conservatiedoeleinden en bij het maken van betere voorspellingen.

Soms moeten soorten veranderen van voedsel als hun normale voedselbron bijvoorbeeld sterk afneemt, als andere soorten die hetzelfde voedsel nuttigen plots toenemen in aantal of als soorten van gebied moeten veranderen door gewijzigde biotische of abiotische omstandigheden. Vaak treden er daarvoor genetische veranderingen op of eventueel veranderingen in de darmflora van het organisme. Bovendien zijn er heel wat factoren die een invloed kunnen hebben op de aanpassingen, zoals bijvoorbeeld interacties met andere soorten.
Door middel van experimenten met een geleedpotig modelorganisme, de bonenspintmijt of Tetranychus urticae, hebben we onderzocht hoe verschillen in ruimtelijke- of gemeenschapscontext adaptatie aan een nieuwe voedselbron kunnen beïnvloeden. De ruimtelijke context in dit onderzoek kan zowel duiden op een eerder homogene of heterogene omgeving, alsook op verschillen in dispersie. De onderzochte populatie bonenspintmijten kwam aanvankelijk enkel voor in een homogene omgeving, de initiële voedselbron van deze soort was immers enkel de

bonenplant. In het onderzoek werden de onderzochte bonenspintmijten in een nieuwe homogene of heterogene omgeving (meerdere plantensoorten samen) geplaatst. De populatie kreeg hiertoe nieuwe plantensoorten zoals komkommer-, tomaten- en paprikaplanten ter beschikking, waaraan de bonenspintmijten zich al dan niet konden aanpassen. Dispersie duidt op het aantal bonenspintmijten dat per week van de oorspronkelijke populatie (op bonenplanten) werd overgezet naar de nieuwe plantensoort. Dit is onderdeel van de ruimtelijke context, omdat het een idee geeft over de afstand tussen de populaties: hoe meer mijten overgezet worden, hoe kleiner de afstand tussen de populaties. Met de gemeenschapscontext bedoelen we de aanwezigheid van een andere soort tijdens de adaptatie (interspecifieke competitie) of de invloed van het aanwezige microbioom (de micro-organismen die in de spintmijten leven en er mogelijk helpen bij de vertering en detoxificatie van voedsel).

In het eerste hoofdstuk beschrijven we het onderzoek naar de invloed van dispersie en competitie op de aanpassing van de bonenspintmijt aan een nieuwe voedselbron, de tomatenplant. We ontdekten dat het wekelijks overzetten van grote aantallen spintmijten van de oorspronkelijke bonenplant nefast was voor de adaptatie aan tomaat. Dit kon vooral verklaard worden door een 'genetic load', hiermee wordt bedoeld dat er te veel onaangepaste allelen (varianten van genen) de aanpassing aan de nieuwe condities gaan tegenwerken. Verder vonden we dat de toevoeging van een andere soort die al aangepast was aan de nieuwe plantensoort (de tomatenspintmijt of T. evansi) dit nadelige effect tegenging. Deze andere soort creëerde namelijk een moeilijkere omgeving en een grotere sterfte in de populatie bonenspintmijten die adaptatie onderging. Als compensatie was een groter aantal spintmijten per week vereist. Dit grotere aantal kon helpen bij het aanvullen van de populatie en vergrootte de kans op voordelige allelen voor adaptatie. We konden hiermee aantonen dat het noodzakelijk is om zowel de gemeenschaps- als de ruimtelijke context te combineren om een goed inzicht te krijgen in adaptatie.
Tijdens dit experiment werden zowel de veranderingen in prestatie (aantal gelegde eitjes en levensduur; ook wel evolutionaire dynamieken genoemd) als de populatiegroei (of ecologische dynamieken) opgevolgd. Hetzelfde werd gedaan in een ander experiment dat geen onderdeel is van deze thesis (Alzate, Etienne & Bonte, 2019). Beide experimenten gaven ons de mogelijkheid om met behulp van een wiskundig model te onderzoeken hoe evolutionaire adaptatie de draagkracht en groeisnelheid van een populatie kan beïnvloeden (hoofdstuk 2). We konden aantonen dat de draagkracht van de populatie afnam naarmate de populatie beter aangepast was aan de nieuwe omgeving, daarnaast vonden we een toename in de groeisnelheid. Wellicht is dit omdat individuen die beter aangepast waren meer voedsel opnamen, zodat er minder voedsel beschikbaar was voor de overige individuen van de populatie. De extra verworven energie door de hogere voedselinname kon geïnvesteerd worden in een grotere populatiegroei. Dit onderzoek is een mooi voorbeeld van hoe evolutie een effect kan hebben op ecologische dynamieken.

Soms gaan experimenten niet helemaal zoals je het zou willen, maar leiden ze het desalniettemin tot interessante resultaten, zoals in het derde hoofdstuk. Hier wordt het onderzoek beschreven dat wilde nagaan wat de invloed was van een andere mijtensoort op adaptatie, maar deze keer een soort die nog niet aangepast was. Onze gekozen competitor, T. ludeni of rode spintmijt, stierf helaas uit in ons experiment en wordt daarom in onze studie een geest genoemd. Dit gaf ons de mogelijkheid om te onderzoeken wat de invloed was van initiële selectiedrukken zoals geestcompetitie op adaptatie aan een nieuwe omgeving. Bij sommige populaties bonenspintmijten slaagde de rode spintmijt er initieel wel in om een hogere densiteit te halen. Deze populaties presteerden na 25 generaties nog steeds beter op vlak van fecunditeit dan andere populaties bonenspintmijten. We konden hiermee aantonen dat initiële competitie van een onsuccesvolle soort een langdurig effect kan hebben op adaptatie van een andere soort.

Het vierde hoofdstuk behandelt het onderzoek van opnieuw een combinatie van een ruimtelijke en een gemeenschapscontext, meer specifiek een homogene of heterogene omgeving en competitie. We gebruikten een vrij gemakkelijke voedselbron, komkommer, en de meer uitdagende paprikaplant (door zijn toxische substanties en glandulaire trichomen). De rode spintmijt stierf snel uit en leverde geen nieuwe inzichten op, de variatie in plantensoorten daarentegen was intrigerend. We konden aantonen dat een eerder heterogene omgeving adaptatie aan moeilijke condities kan vergemakkelijken door als het ware een soort evolutionaire stapsteen aan te bieden. Dit betekent dat er voldoende individuen in leven kunnen blijven op de gemakkelijkere voedselbron en op deze manier een populatie in stand houdt die gunstige allelen kan hebben voor aanpassing aan de uitdagende voedselbron. Deze adaptatie was echter kortstondig. Naarmate de populatie op de gemakkelijkere voedselbron uitbreidde, kwamen meer en meer onaangepaste individuen op de paprikaplant terecht die de adaptatie aan paprika teniet deden (‘genetic load’, zoals beschreven in het eerste hoofdstuk). Adaptatie aan moeilijkere condities kan dus gemakkelijker optreden in heterogene omgevingen, maar is sterk afhankelijk van hoe en hoeveel individuen doorheen het landschap bewegen.

Hierboven werd al vermeld dat het microbioom kan helpen bij het verteren en ontgiften van voedsel, wat het erg waardevol maakt. Hierdoor kunnen deze bacteriën hun gastheer helpen om zich aan te passen aan veranderende omstandigheden. In het vijfde hoofdstuk bespreken we het verdere onderzoek hiernaar met behulp van een evolutionair experiment, door bonenspintmijten zich te laten aanpassen aan twee nieuwe voedselbronnen, nl. komkommerplanten en tomatenplanten. Zowel het microbioom als de fecunditeit en levensduur op de verschillende plantensoorten werden hierbij opgevolgd. We konden aantonen dat het microbioom slechts gedeeltelijk verklaard kan worden door de afkomst en voedselbron van zijn gastheer, maar dus mogelijk voor een groot deel door ongekende factoren wordt beïnvloed. Daarnaast vonden we een correlatie tussen fecunditeit en levensduur op de nieuwe voedselbronnen en het microbioom op deze plantensoorten. Dit toont aan dat de

micro-organismen niet vergeten mogen worden bij onderzoek naar aanpassingsvermogen van soorten.

Geïntrigeerd door de inzichten van het microbioom uit een experimentele omgeving, wouden we dit graag ook onderzoeken in een natuurlijke setting. Hiervoor hebben we veldwerk verricht op microlandslakken op kalksteenheuvels in Maleisisch Borneo. Het doel van dit onderzoek was om interacties te onderzoeken tussen gemeenschappen van slakken, hun dieet en hun microbioom. Onze resultaten toonden aan dat er nauwelijks een correlatie was tussen de slakkengemeenschap en hun dieet, maar dat het microbioom positief gecorreleerd was aan beide. Dit betekent dus dat slakken die leven in een gemeenschap bestaande uit veel verschillende slakkensoorten doorgaans een rijker microbioom hebben, maar ook dat een rijk microbioom gecorreleerd is aan een meer gevarieerd dieet. Daarnaast merkten we dat omgevingsfactoren zoals de grootte van het gebied, de aanwezigheid van grotten en vooral menselijke activiteit een invloed hadden op de slakkengemeenschap, hun dieet en hun microbioom.

Samengevat, adaptatie is een heel complex proces en wordt voor een groot deel beïnvloed door de ruimtelijke- en gemeenschapscontext. In deze thesis hebben we geprobeerd om het proces verder te ontrafelen. Hoewel we in staat waren om meer inzicht te geven in de invloed van dispersie, competitie en het microbioom, is dit slechts de tip van de ijsberg en is vervolgonderzoek aan de orde.

References

Abrams, P.A. 2019. How does the evolution of universal ecological traits affect population size? Lessons from simple models. *Am. Nat.* **193**: 1–16.

Adango, E., Onzo, A., Hanna, R., Atachi, P. & James, B. 2006. Comparative demography of the spider mite, *Tetranychus ludeni*on two host plants in West Africa. *J. Insect Sci.* **6**: 1–9.

Agrawal, A.A. 2000. Host-range evolution: adaptation and trade-offs in fitness of mites on alternative hosts. *Ecology* **81**: 500–508.

Allen, A.P., Whittier, T.R., Kaufmann, P.R., Larsen, D.P., O'Connor, R.J., Hughes, R.M., *et al.* 1999. Concordance of taxonomic richness patterns across multiple assemblages in lakes of the northeastern United States. *Can. J. Fish. Aquat. Sci.* **56**: 739–747.

Allendorf, F.W., Luikart, G.H. & Aitken, S.N. 2013. *Conservation and the genetics of populations*, 2nd ed. Wiley-Blackwell.

Alzate, A., Bisschop, K., Etienne, R.S. & Bonte, D. 2017. Interspecific competition counteracts negative effects of dispersal on adaptation of an arthropod herbivore to a new host. *J. Evol. Biol.* **30**: 1966–1977.

Alzate, A., Etienne, R.S. & Bonte, D. 2019. Experimental island biogeography demonstrates the importance of island size and dispersal for the adaptation to novel habitats. *Glob. Ecol Biogeogr* **28**: 238–247.

Amarasekare, P. 2003. Competitive coexistence in spatially structured environments: A synthesis. *Ecol. Lett.* **6**: 1109–1122. Wiley/Blackwell (10.1111).

Anderson, M.J. 2017. Permutational Multivariate Analysis of Variance (PERMANOVA). *Wiley StatsRef Stat. Ref. Online* 1–15.

Anderson, M.J., Walsh, D.C.I., Robert Clarke, K., Gorley, R.N. & Guerra-Castro, E. 2017. Some solutions to the multivariate Behrens–Fisher problem for dissimilarity-based analyses. *Aust. New Zeal. J. Stat.* **59**: 57–79.

Archie, E.A. & Theis, K.R. 2011. Animal behaviour meets microbial ecology. *Anim. Behav.* **82**: 425–436.

Baiser, B., Olden, J.D., Record, S., Lockwood, J.L. & Mckinney, M.L. 2012. Pattern and process of biotic homogenization in the New Pangaea. *Proc. R. Soc. B* **279**: 4772–4777.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., *et al.* 2011. Has the Earth's sixth mass extinction already arrived? *Nature* **471**: 51–57.

Barrett, R.D.H. & Schluter, D. 2008. Adaptation from standing genetic variation. *Trends Ecol. Evol.* **23**: 38–44.

Bartoń, K.A. 2015. MuMIn: multi-model inference. R package version 1.15.1.

Bartoń, K.A. 2018. MuMIn: multi-model inference. R package version 1.42.1.

Bartoń, K.A. 2019. MuMIn: multi-model inference. R package version 1.43.6.

Bates, D., Maechler, M., Bolker, B.M. & Walker, S. 2015. Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* **67**: 1–48.

Baumann, P. 2005. Biology of Bacteriocyte-Associated Endosymbionts of Plant Sap-Sucking Insects. *Annu. Rev. Microbiol.* **59**: 155–189.

Beaudrot, L., Struebig, M.J., Meijaard, E., van Balen, S., Husson, S. & Marshall, A.J. 2013. Co-occurrence patterns of Bornean vertebrates suggest competitive exclusion is strongest among distantly related species. *Oecologia* **173**: 1053–1062.

Becks, L., Ellner, S.P., Jones, L.E. & Hairston Jr., N.G. 2010. Reduction of adaptive genetic diversity radically alters eco-evolutionary community dynamics. *Ecol. Lett.* **13**: 989–997. John Wiley & Sons, Ltd (10.1111).

Becks, L., Ellner, S.P., Jones, L.E. & Hairston Jr., N.G. 2012. The functional genomics of an eco-evolutionary feedback loop: linking gene expression, trait evolution, and community dynamics. *Ecol. Lett.* **15**: 492–501. John Wiley & Sons, Ltd (10.1111).

Bell, G. & Gonzalez, A. 2011. Adaptation and evolutionary rescue in metapopulations experiencing environmental deterioration. *Science (80-.).* **332**: 1327–1330.

Bell, K.L., Loeffler, V.M. & Brosi, B.J. 2017. An *rbcL* reference library to aid in the identification of plant species mixtures by DNA metabarcoding. *Appl. Plant Sci.* **5**: 1600110. John Wiley & Sons, Ltd.

Belliure, B., Montserrat, M. & Magalhães, S. 2010. Mites as models for experimental evolution studies. *Acarologia* **50**: 513–529.

Bengtsson, J. 1989. Interspecific competition increases local extinction rate in a metapopulation system. *Nature* **340**: 713–715. Nature Publishing Group.

Bennett, J.A., Lamb, E.G., Hall, J.C., Cardinal-Mcteague, W.M. & Cahill, J.F. 2013. Increased competition does not lead to increased phylogenetic overdispersion in a native grassland. *Ecol. Lett.* **16**: 1168–1176.

Berendsen, R.L., Pieterse, C.M.J. & Bakker, P.A.H.M. 2012. The rhizosphere microbiome and plant health. *Trends Plant Sci.* **17**: 478–486.

Best, A.S., Johst, K., Münkemüller, T. & Travis, J.M.J. 2007. Which species will succesfully track climate change? The influence of intraspecific competition and density dependent dispersal on range shifting dynamics. *Oikos* **116**: 1531–1539.

Bisschop, K., Mortier, F., Bonte, D. & Etienne, R.S. 2019a. Performance in a novel environment subject to ghost competition. *bioRxiv* 515833. Cold Spring Harbor Laboratory.

Bisschop, K., Mortier, F., Etienne, R.S. & Bonte, D. 2019b. Transient local adaptation and source–sink dynamics in experimental populations experiencing spatially heterogeneous environments. *Proc. R. Soc. B Biol. Sci.* **286**: 20190738.

Bitume, E. V., Bonte, D., Ronce, O., Bach, F., Flaven, E., Olivieri, I., *et al.* 2013. Density and genetic relatedness increase dispersal distance in a subsocial organism. *Ecol. Lett.* **16**: 430–437.

Bitume, E. V., Bonte, D., Ronce, O., Olivieri, I. & Nieberding, C.M. 2014. Dispersal distance is influenced by parental and grand-parental density. *Proc. R. Soc. B Biol. Sci.* **281**: 20141061–20141061.

Blanquart, F., Gandon, S. & Nuismer, S.L. 2012. The effects of migration and drift on local adaptation to a heterogeneous environment. *J. Evol. Biol.* **25**: 1351–1363.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Henry, M., *et al.* 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol. Evol.* **24**: 127–135.

Bolland, H.R., Gutiérrez, J. & Flechtmann, C.H.W. 1998. *World Catalogue of the spider mite family (Acari: Tetranychidae); with references to taxonomy, synonymy host plants and distribution*. Brill.

Bolnick, D.I. 2001. Intraspecific competition favours niche width expansion in Drosophila melanogaster. *Nature* **410**: 463–466.

Bolnick, D.I. & Nosil, P. 2007. Natural selection in populations subject to a migration load. *Evolution (N. Y).* **61**: 2229–2243.

Bolyen, E., Rideout, J.R., Dillon, M.R., Bokulich, N.A., Abnet, C., Al-Ghalith, G.A., *et al.* 2018. QIIME 2: Reproducible, interactive, scalable, and extensible microbiome data science. , doi: 10.7287/peerj.preprints.27295v2. PeerJ Inc.

Bonato, O. 1999. *The effect of temperature on life history parameters of Tetranychus evansi (Acari: Tetranychidae)*.

Bonte, D. & Bafort, Q. 2019. The importance and adaptive value of life-history evolution for metapopulation dynamics. *J. Anim. Ecol.* **88**: 24–34. John Wiley & Sons, Ltd (10.1111).

Bonte, D., De Roissart, A., Vandegehuchte, M.L., Ballhorn, D.J., van Leeuwen, T. & de la Peña, E. 2010. Local adaptation of aboveground herbivores towards plant phenotypes induced by soil biota. *PLoS One* **5**: e11174.

Bonte, D., De Roissart, A., Wybouw, N. & Van Leeuwen, T. 2014. Fitness maximization by dispersal: evidence from an invasion experiment. *Ecology* **95**: 3104–3111.

Bonte, D., Masier, S. & Mortier, F. 2018. Eco-evolutionary feedbacks following changes in spatial connectedness. *Curr. Opin. Insect Sci.* **29**: 64–70. Elsevier.

Bordenstein, S.R., O'Hara, F.P. & Werren, J.H. 2001. *Wolbachia*-induced incompatibility precedes other hybrid incompatibilities in *Nasonia*. *Nature* **409**: 707–710.

Bordenstein, S.R. & Theis, K.R. 2015. Host biology in light of the microbiome: Ten principles of holobionts and hologenomes. *PLoS Biol.* **13**: e1002226.

Bossdorf, O., Richards, C.L. & Pigliucci, M. 2007. Epigenetics for ecologists. *Ecol. Lett.* **11**: 106–115.

Bourtzis, K., Nirgianaki, A., Markakis, G. & Savakis, C. 1996. *Wolbachia* infection and cytoplasmic incompatibility in *Drosophila* species. *Genetics* **144**: 1063–1073.

Bray, J.R. & Curtis, J.T. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.* **27**: 327–349.

Breeuwer, J.A.J. & Jacobs, G. 1996. Wolbachia: intercellular manipulators of mite reproduction. *Exp. Appl.*

Acarol. **20**: 421–434.
Brinker, P., Fointaine, M.C., Beukeboom, L.W. & Salles, J.F. 2019. Host, symbionts, and the microbiome: the missing tripartite interaction. *Trends Microbiol.*, doi: 10.1016/j.tim.2019.02.002.
Broderick, N.A., Raffa, K.F., Goodman, R.M. & Handelsman, J. 2004. Census of the Bacterial Community of the Gypsy Moth Larval Midgut by Using Culturing and Culture-Independent Methods. *Appl. Environ. Microbiol.* **70**: 293–300.
Brons, J.K. & Dirk Van Elsas, J. 2008. Analysis of bacterial communities in soil by use of denaturing gradient gel electrophoresis and clone libraries, as influenced by different reverse primers. *Appl. Environ. Microbiol.* **74**: 2717–2727.
Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., *et al.* 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R J.* **9**: 378–400.
Brown, J.H. & Kodric-Brown, A. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. *Ecology* **58**: 445–449.
Brucker, R.M. & Bordenstein, S.R. 2013. The hologenomic basis of speciation: Gut bacteria cause hybrid lethality in the genus Nasonia. *Science (80-.).* **341**: 667–669.
Bruijning, M., Jongejans, E. & Turcotte, M.M. 2019. Demographic responses underlying eco-evolutionary dynamics as revealed with inverse modelling. *J. Anim. Ecol.* 1365-2656.12966. John Wiley & Sons, Ltd (10.1111).
Bruvo, R., Michiels, N.K., D'Souza, T.G. & Schulenberg, H. 2004. A simple method for the calculation of microsatellite genotype distances irrespective of ploidy level. *Mol. Ecol.* **13**: 2101–2106. John Wiley & Sons, Ltd (10.1111).
Buckling, A., Wills, M.A. & Colegrave, N. 2003. Adaptation limits diversification of experimental bacterial populations. *Science (80-.).* **302**: 2107–2109.
Bullock, J.M., Bonte, D., Pufal, G., da Silva Carvalho, C., Chapman, D.S., García, C., *et al.* 2018. Human-mediated dispersal and the rewiring of spatial networks. *Trends Ecol. Evol.* **33**: 958–970.
Burns, J.H., Ashman, T.L., Steets, J.A., Harmon-Threatt, A. & Knight, T.M. 2011. A phylogenetically controlled analysis of the roles of reproductive traits in plant invasions. *Oecologia* **166**: 1009–1017.
Burns, J.H. & Strauss, S.Y. 2011. More closely related species are more ecologically similar in an experimental test. *Proc. Natl. Acad. Sci.* **108**: 5302–5307.
Cadotte, M.W. 2006. Dispersal and species diversity: a meta-analysis. *Am. Nat.* **167**: 913–924.
Calcagno, V., Mouquet, N., Jarne, P. & David, P. 2006. Coexistence in a metacommunity: the competition-colonization trade-off is not dead. *Ecol. Lett.* **9**: 897–907.
Callahan, B.J., McMurdie, P.J., Rosen, M.J., Han, A.W., Johnson, A.J.A. & Holmes, S.P. 2016. DADA2: High-resolution sample inference from Illumina amplicon data. *Nat. Methods* **13**: 581–583.
Capinha, C., Essl, F., Seebens, H., Moser, D. & Pereira, H.M. 2015. The dispersal of alien species redefines biogeography in the Anthropocene. *Science (80-.).* **348**: 1248–1251.
Carlson, S.M., Cunningham, C.J. & Westley, P.A.H. 2014. Evolutionary rescue in a changing world. *Trends Ecol. Evol.* **29**: 521–530.
Case, T.J., Holt, R.D., McPeek, M.A. & Keitt, T.H. 2005. The community context of species' borders: Ecological and evolutionary perspectives. *Oikos* **108**: 28–46.
Cass, B.N., Himler, A.G., Bondy, E.C., Bergen, J.E., Sierra, F.K., Kelly, S.E., *et al.* 2016. Conditional fitness benefits of the Rickettsia bacterial symbiont in an insect pest. *Oecologia* **1**: 169–179.
Chaplinska, M., Gerritsma, S., Dini-Andreote, F., Salles, J.F. & Wertheim, B. 2016. Bacterial communities differ among *Drosophila melanogaster* populations and affect host resistance against parasitoids. *PLoS One* **11**: e167726.
Charlesworth, B. 2009. Effective population size and patterns of molecular evolution and variation. *Nat. Rev. Genet.* **10**: 195–205.
Chesson, P. 2000. Mechanisms of maintenance of species diversity. 343–366.
Chevin, L.M. & Lande, R. 2011. Adaptation to marginal habitats by evolution of increased phenotypic plasticity. *J. Evol. Biol.* **24**: 1462–1476.
Ching, J., Musheyev, S.A., Chowdhury, D., Kim, J.A., Choi, Y. & Dennehy, J.J. 2012. Migration enhances adaptation in bacteriophage populations evolving in ecological sinks. *Evolution (N. Y).* **67**: 10–17.
Clemente, S.H., Santos, I., Ponce, R., Rodrigues, L.R., Varela, S.A.M. & Magalhães, S. 2018. Despite

reproductive interference, the net outcome of reproductive interactions among spider mite species is not necessarily costly. *Behav. Ecol.* **29**: 321–327.
Colman, D.R., Toolson, E.C. & Takacs-Vesbach, C.D. 2012. Do diet and taxonomy influence insect gut bacterial communities? *Mol. Ecol.* **21**: 5124–5137.
Connell, J.H. 1961. The influence of interspecific competition and other factors on the distribution of the barnacle *Chthamalus stellatus*. *Ecology* **42**: 710–723.
Cotoras, D.D., Brewer, M.S., Croucher, P.J.P., Oxford, G.S., Lindberg, D.R. & Gillespie, R.G. 2016. Convergent evolution in the colour polymorphism of *Selkirkiella* spiders (Theridiidae) from the South American temperate rainforest. *Biol. J. Linn. Soc.*, doi: 10.1111/bij.12908. John Wiley & Sons, Ltd (10.1111).
Coulson, T., Tuljapurkar, S. & Childs, D.Z. 2010. Using evolutionary demography to link life history theory, quantitative genetics and population ecology. *J. Anim. Ecol.* **79**: 1226–1240. Wiley/Blackwell (10.1111).
Cuevas, J.M., Moya, A. & Elena, S.F. 2003. Evolution of RNA virus in spatially structured heterogeneous environments. *J. Evol. Biol.* **16**: 456–466.
Dahirel, M., Masier, S., Renault, D. & Bonte, D. 2019. The distinct phenotypic signatures of dispersal and stress in an arthropod model: from physiology to life history. *J. Exp. Biol.* **222**: jeb203596. The Company of Biologists Ltd.
Danchin, É., Charmantier, A., Champagne, F.A., Mesoudi, A., Pujol, B. & Blanchet, S. 2011. Beyond DNA: Integrating inclusive inheritance into an extended theory of evolution. *Nat. Rev. Genet.* **12**: 475–486. Nature Publishing Group.
Darby, A.C. & Douglas, A.E. 2003. Elucidation of the transmission patterns of an insect-borne bacterium. *Appl. Environ. Microbiol.* **69**: 4403–4407.
Darwin, C. 1859. *The origin of species by means of natural selection or the preservation of favoured races in the struggle for life*. John Murray, London.
David, L.A., Maurice, C.F., Carmody, R.N., Gootenberg, D.B., Button, J.E., Wolfe, B.E., *et al.* 2014. Diet rapidly and reproducibly alters the human gut microbiome. *Nature* **505**: 559–563.
De Mazancourt, C., Johnson, E. & Barraclough, T.G. 2008. Biodiversity inhibits species' evolutionary responses to changing environments. *Ecol. Lett.* **11**: 380–388. Wiley/Blackwell (10.1111).
De Meester, L., Brans, K.I., Govaert, L., Souffreau, C., Mukherjee, S., Vanvelk, H., *et al.* 2019. Analyzing eco-evolutionary dynamics - the challenging complexity of the real world. *Funct. Ecol.* **33**: 43–59. John Wiley & Sons, Ltd (10.1111).
De Meester, L., Vanoverbeke, J., Kilsdonk, L.J. & Urban, M.C. 2016. Evolving Perspectives on Monopolization and Priority Effects. *Trends Ecol. Evol.* **31**: 136–146.
De Roissart, A., Wang, S. & Bonte, D. 2015. Spatial and spatiotemporal variation in metapopulation structure affects population dynamics in a passively dispersing arthropod. *J. Anim. Ecol.* **84**: 1565–1574.
De Vasconcelos, G.J.N., De Moraes, G.J., Júnior, Í.D. & Knapp, M. 2008. Life history of the predatory mite Phytoseiulus fragariae on Tetranychus evansi and Tetranychus urticae (Acari: Phytoseiidae, Tetranychidae) at five temperatures. *Exp. Appl. Acarol.* **44**: 27–36.
Declerck, S., Vandekerkhove, J., Johansson, L., Muylaert, K., Conde-Porcuna, J.M., Van Der Gucht, K., *et al.* 2005. Multi-group biodiversity in shallow lakes along gradients of phosphorus and water plant cover. *Ecology* **86**: 1905–1915.
Del Castillo, R.F., Trujillo-Argueta, S., Sánchez-Vargas, N. & Newton, A.C. 2011. Genetic factors associated with population size may increase extinction risks and decrease colonization potential in a keystone tropical pine. *Evol. Appl.* **4**: 574–588.
Delignette-Muller, M.L. 2015. fitdistrplus: an R package for fitting distributions. *J. Stat. Softw.* **64**: 1–34.
Dermauw, W., Pym, A., Bass, C., Van Leeuwen, T. & Feyereisen, R. 2018. Does host plant adaptation lead to pesticide resistance in generalist herbivores? *Curr. Opin. Insect Sci.* **26**: 25–33.
Des Roches, S., Post, D.M., Turley, N.E., Bailey, J.K., Hendry, A.P., Kinnison, M.T., *et al.* 2018. The ecological importance of intraspecific variation. *Nat. Ecol. Evol.* **2**: 57–64.
DeSantis, T.Z., Hugenholtz, P., Larsen, N., Rojas, M., Brodie, E.L., Keller, K., *et al.* 2006. Greengenes, a chimera-checked 16S rRNA gene database and workbench compatible with ARB. *Appl. Environ. Microbiol.* **72**: 5069–5072.
Després, L., David, J.P. & Gallet, C. 2007. The evolutionary ecology of insect resistance to plant chemicals.

Trends Ecol. Evol. **22**: 298–307.
Diamond, J., Pimm, S.L., Gilpin, M.E. & LeCroy, M. 1989. Rapid evolution of character displacement in Myzomelid honeyeaters. *Am. Nat.* **134**: 675–708.
Diamond, J.M. 1975. Assembly of species communities. In: *Ecology and evolution of cummunities* (J. M. Diamond & M. L. Cody, eds), pp. 342–344. Harvard University Press, Boston.
Dörge, N., Walther, C., Beinlich, B. & Plachter, H. 1999. The significance of passive transport for dispersal in terrestrial snails (Gastropoda, Pulmonata). *Zeitschrift für Ökologie und Naturschutz* **8**: 11–10.
Dornelas, M., Gotelli, N.J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C., *et al.* 2014. Assemblage time series reveal biodiversity change but not systematic loss. *Science (80-.).* **344**: 296–299.
Dykstra, H.R., Weldon, S.R., Martinez, A.J., White, J.A., Hopper, K.R., Heimpel, G.E., *et al.* 2014. Factors limiting the spread of the protective symbiont Hamiltonella defensa in Aphis craccivora aphids. *Appl. Environ. Microbiol.* **80**: 5818–5827.
Ebert, D. 2013. The epidemiology and evolution of symbionts with mixed-mode transmission. *Annu. Rev. Ecol. Evol. Syst.* **44**: 623–643.
Egas, M. & Sabelis, M.W. 2001. Adaptive learning of host preference in a herbivorous arthropod. *Ecol. Lett.* **4**: 190–195.
Engel, P. & Moran, N.A. 2013. The gut microbiota of insects-diversity in structure and function. *FEMS Microbiol. Rev.* **37**: 699–735.
Enigl, M. & Schausberger, P. 2007. Incidence of the endosymbionts *Wolbachia*, *Cardinium* and *Spiroplasma* in phytoseiid mites and associated prey. *Exp. Appl. Acarol.* **42**: 75–85.
Etienne, R.S. & Haegeman, B. 2019. *DDD: Diversity-Dependent Diversification. R package version 4.1*.
Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: A synthesis. *Ecol. Appl.* **12**: 346–353. Annual Reviews 4139 El Camino Way, P.O. Box 10139, Palo Alto, CA 94303-0139, USA .
Faith, D.P. 1992. Conservation evaluation and phylogenetic diversity. *Biol. Conserv.* **61**: 1–10.
Fanelli, D. 2012. Negative results are disappearing from most disciplines and countries. *Scientometrics* **90**: 891–904.
Ferriere, R. & Legendre, S. 2013. Eco-evolutionary feedbacks, adaptive dynamics and evolutionary rescue theory. *Philos. Trans. R. Soc. B Biol. Sci.* **368**: 20120081.
Fine, P.V.A. 2002. The invasibility of tropical forests by exotic plants. *J. Trop. Ecol.* **18**: 687–705.
Fisher, R.A. 1930. *The genetical theory of natural selection*. Oxford University Press.
Fitzpatrick, S.W., Gerberich, J.C., Angeloni, L.M., Bailey, L.L., Broder, E.D., Torres-Dowdall, J., *et al.* 2016. Gene flow from an adaptively divergent source causes rescue through genetic and demographic factors in two wild populations of Trinidadian guppies. *Evol. Appl.* **9**: 879–891. Wiley/Blackwell (10.1111).
Forester, B.R., Jones, M.R., Joost, S., Landguth, E.L. & Lasky, J.R. 2016. Detecting spatial genetic signatures of local adaptation in heterogeneous landscapes. *Mol. Ecol.* **25**: 104–120. Wiley/Blackwell (10.1111).
Franchini, P., Fruciano, C., Frickey, T., Jones, J.C. & Meyer, A. 2014. The gut microbial community of Midas cichlid fish in repeatedly evolved limnetic-benthic species Pairs. *PLoS One* **9**: e95027.
Fry, J.D. 1989. Evolutionary adaptation to host plants in a laboratory population of the phytophagous mite *Tetranychus urticae* Koch. *Oecologia* **81**: 559–565.
Fukami, T. 2015. Historical contingency in community assembly: integrating niches, species pools, and priority effects. *Annu. Rev. Ecol. Evol. Syst.* **46**: 1–23.
Furrer, R.D. & Pasinelli, G. 2016. Empirical evidence for source-sink populations: a review on occurrence, assessments and implications. *Biol. Rev. Camb. Philos. Soc.* **91**: 782–795. Wiley/Blackwell (10.1111).
Fussmann, G.F., Loreau, M. & Abrams, P.A. 2007. Eco-evolutionary dynamics of communities and ecosystems. *Funct. Ecol.* **21**: 465–477. Wiley/Blackwell (10.1111).
Futuyma, D.J. 2009. *Evolution*. Sinauer Associations, Massachusetts.
Gagnon, K., Rothäusler, E., Syrjänen, A., Yli-Renko, M. & Jormalainen, V. 2013. Seabird guano fertilizes baltic sea littoral food webs. *PLoS One* **8**: 61284.
Galenza, A., Hutchinson, J., Campbell, S.D., Hazes, B. & Foley, E. 2016. Glucose modulates *Drosophila* longevity and immunity independent of the microbiota. *Biol. Open* **5**: 165–173.
Garant, D., Forde, S.E. & Hendry, A.P. 2007. The multifarious effects of dispersal and gene flow on contemporary adaptation. *Funct. Ecol.* **21**: 434–443. John Wiley & Sons, Ltd (10.1111).

Gause, G.F. 1934. *The struggle for existence*, 1st ed. Williams and Wilkins, Baltimore, MD.
Gause, G.F. & Witt, A.A. 1935. Behaviour of mixed populations and the problem of natural selection. *Am. Nat.* **69**: 596–609.
Gibson, G. & Dworkin, I. 2004. Uncovering cryptic genetic variation. *Nat. Rev. Genet.* **5**: 681–690.
Glasl, B., Smith, C.E., Bourne, D.G. & Webster, N.S. 2018. Exploring the diversity-stability paradigm using sponge microbial communities. *Sci. Rep.* **8**: 8425. Nature Publishing Group.
Godinho, D.P., Janssen, A., Dias, T., Cruz, C. & Magalhães, S. 2016. Down-regulation of plant defence in a resident spider mite species and its effect upon con- and heterospecifics. *Oecologia* **180**: 161–167. Springer Berlin Heidelberg.
Gotoh, T., Bruin, J., Sabelis, M.W. & Menken, S.B.J. 1993. Host race formation in *Tetranychus urticae*: genetic differentiation, host plant preference, and mate choice in a tomato and a cucumber strain. *Entomol. Exp. Appl.* **68**: 171–178. Wiley/Blackwell (10.1111).
Gotoh, T., Noda, H. & Hong, X.-Y. 2003. Wolbachia distribution and cytoplasmic incompatibility based on a survey of 42 spider mite species (Acari: Tetranychidae) in Japan. *Heredity (Edinb).* **91**: 208–216.
Gotoh, T., Noda, H. & Ito, S. 2007. Cardinium symbionts cause cytoplasmic incompatibility in spider mites. *Heredity (Edinb).* **98**: 13–20.
Gould, F. 1979. Rapid host range evolution in a population of the phytophagous mite *Tetranychus urticae* Koch. *Evolution (N. Y).* **33**: 791–802. Wiley/Blackwell (10.1111).
Govaert, L., Fronhofer, E.A., Lion, S., Eizaguirre, C., Bonte, D., Egas, M., *et al.* 2019. Eco-evolutionary feedbacks - theoretical models and perspectives. *Funct. Ecol.* **33**: 13–30.
Grbić, M., Khila, A., Lee, K.-Z., Bjelica, A., Grbić, V., Whistlecraft, J., *et al.* 2007. Mity model:Tetranychus urticae, a candidate for chelicerate model organism. *BioEssays* **29**: 489–496. John Wiley & Sons, Ltd.
Grbić, M., Van Leeuwen, T., Clark, R.M., Rombauts, S., Rouzé, P., Grbić, V., *et al.* 2011. The genome of Tetranychus urticae reveals herbivorous pest adaptations. *Nature* **479**: 487–492.
Griffis, M.R. & Jaeger, R.G. 1998. Competition leads to an extinction-prone species of salamander: Interspecific territoriality in a metapopulation. *Ecology* **79**: 2494–2502. Ecological Society of America.
Grizard, S., Dini-Andreote, F., Tieleman, B.I. & Salles, J.F. 2014. Dynamics of bacterial and fungal communities associated with eggshells during incubation. *Ecol. Evol.* **4**: 1140–1157.
Guidolin, A.S., Cataldi, T.R., Labate, C.A., Francis, F. & Cônsoli, F.L. 2018. *Spiroplasma* affects host aphid proteomics feeding on two nutritional resources. *Nat. Sci. Reports* **8**: 1–13.
Haddad, N.M., Crutsinger, G.M., Gross, K., Haarstad, J., Knops, J.M.H. & Tilman, D. 2009. Plant species loss decreases arthropod diversity and shifts trophic structure. *Ecol. Lett.* **12**: 1029–1039. John Wiley & Sons, Ltd (10.1111).
Haddad, N.M., Tilman, D., Haarstad, J., Ritchie, M. & Knops, J.M.H. 2001. Contrasting effects of plant richness and composition on insect communities: a field experiment. *Am. Nat.* **158**: 17–35.
Hafer, N. & Vorburger, C. 2019. Diversity begets diversity: do parasites promote variation in protective symbionts? *Curr. Opin. Insect Sci.* **32**: 8–14.
Hairston Jr., N.G., Ellner, S.P., Geber, M.A., Yoshida, T. & Fox, J.A. 2005. Rapid evolution and the convergence of ecological and evolutionary time. *Ecol. Lett.* **8**: 1114–1127.
Haldane, J.B.S. 1932. *The causes of evolution*. Longmans, London.
Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., *et al.* 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS One* **12**: e0185809.
Hance, T. & Van Impe, G. 1999. *The influence of initial age structure on predator-prey interaction*.
Hardin, G. 1960. The competitive exclusion principle. *Science (80-.).* **131**: 1292–1297.
Hardin, J.W. & Hilbe, J.M. 2007. *Generalized Linear Models and Extensions*, 2nd editio. Stata Press, Texas.
Hawkes, C. V. & Keitt, T.H. 2015. Resilience vs. historical contingency in microbial responses to environmental change. *Ecol. Lett.* **18**: 612–625.
Hawkins, B.A. & Porter, E.E. 2003. Does herbivore diversity depend on plant diversity? The case of California butterflies. *Am. Nat.* **161**.
Heil, M. 2008. Indirect defence via tritrophic interactions. *New Phytol.* **178**: 41–61.
Helmus, M.R., Mahler, D.L. & Losos, J.B. 2014. Island biogeography of the Anthropocene. *Nature* **513**: 543–546.

Hendriks, K.P., Alciatore, G., Schilthuizen, M. & Etienne, R.S. 2019a. Phylogeography of Bornean land snails suggests long-distance dispersal as a cause of endemism. *J. Biogeogr.* **46**: 932–944. John Wiley & Sons, Ltd (10.1111).

Hendriks, K.P., Bisschop, K., Kavanagh, J.C., Kortenbosch, H.H., Larue, A.E.A., Richter Mendoza, F.J., *et al.* 2019b. Fieldwork to sample microsnails for diet and microbiome studies along the Kinabatangan River, Sabah, Malaysian Borneo. *Malacol.* **72**: 33–38.

Hendry, A.P. 2019. A critique for eco-evolutionary dynamics. *Funct. Ecol.* **33**: 84–94. John Wiley & Sons, Ltd (10.1111).

Hendry, A.P. 2016. *Eco-evolutionary dynamics*. Princeton University Press.

Henry, L.M., Peccoud, J., Simon, J.-C., Hadfield, J.D., Maiden, M.J.C., Ferrari, J., *et al.* 2013. Horizontally transmitted symbionts and host colonization of ecological niches. *Curr. Biol.* **23**: 1713–1717.

Hiltunen, T. & Becks, L. 2014. Consumer co-evolution as an important component of the eco-evolutionary feedback. *Nat. Commun.* **5**: 5226.

Hiltunen, T., Hairston Jr., N.G., Hooker, G., Jones, L.E. & Ellner, S.P. 2014. A newly discovered role of evolution in previously published consumer-resource dynamics. *Ecol. Lett.* **17**: 915–923. John Wiley & Sons, Ltd (10.1111).

Hird, S.M., Ganz, H., Eisen, J.A. & Boyce, W.M. 2018. The cloacal microbiome of five wild duck species varies by species and influenza A virus infection status. *mSphere* **3**: e00382-18.

Holmes, E.E. & Wilson, H.B. 1998. Running from trouble: long-distance dispersal and the competitive coexistence of inferior species. *Am. Nat.* **151**: 578–586.

Holt, R.D. 1987. On the relation between niche overlap and competition: the effect of incommensurable niche dimensions. *Oikos* **48**: 110–114.

Holt, R.D. 1984. Spatial heterogeneity, indirect interactions, and the coexistence of prey species. *Am. Nat.* **124**: 377–406.

Holt, R.D. & Gomulkiewicz, R. 1997. How does immigration influence local adaptation? A reexamination of a familiar paradigm. *Am. Nat.* **149**: 563–572.

Holt, R.D. & Gomulkiewicz, R. 1996. The evolution of species' niches: a population dynamic perspective. In: *Case studies in mathematical modelling* (H. G. Othmer, F. R. Adler, M. A. Lewis, & L. C. Dallon, eds), pp. 25–50. Prentice-Hall, New Jersey.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., *et al.* 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol. Monogr.* **75**: 3–35.

Hothorn, T., Bretz, F. & Westfall, P. 2008. Simultaneous inference in general parametric models. *Biometrical J.* **50**: 346–363.

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., *et al.* 2003. Climate change, human impacts, and the resilience of coral reefs. *Science (80-.).* **301**: 929–933.

Huisman, J. & Weissing, F.J. 1999. Biodiversity of plankton by species oscillations and chaos. *Nature* **402**: 407–410. Nature Publishing Group.

Hulme, P.E. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *J. Appl. Ecol.* **46**: 10–18. John Wiley & Sons, Ltd (10.1111).

Hunt, J., Bussière, L.F., Jennions, M.D. & Brooks, R. 2004. What is genetic quality? *Trends Ecol. Evol.* **19**: 329–333.

Hunt, J. & Hodgson, D. 2010. What is fitness, and how do we measure it? In: *Evolutionary Behavioral Ecology* (D. F. Westneat & C. W. Fox, eds). Oxford University Press, New York.

Husar, S.L. 1976. Behavioral character displacement: evidence of food partitioning in insectivorous bats. *J. Mammal.* **57**: 331–338.

Hutchinson, G.E. 1957. Concluding Remarks. *Cold Spring Harb. Symp. Quant. Biol.* **22**: 415–427.

Hutchinson, G.E. 1959. Homage to Santa Rosalia or why are there so many kinds of animals? *Am. Nat.* **93**: 145–159.

Hutchinson, G.E. 1961. The paradox of the plankton. *Am. Nat.* **95**: 137–145.

Huttenhower, C., Gevers, D., Knight, R., Abubucker, S., Badger, J.H., Chinwalla, A.T., *et al.* 2012. Structure, function and diversity of the healthy human microbiome. *Nature* **486**: 207–214.

Irigoien, X., Huisman, J. & Harris, R.P. 2004. Global biodiversity patterns of marine phytoplankton and zooplankton. *Nature* **429**: 863–867.

Jacob, S., Legrand, D., Chaine, A.S., Bonte, D., Schtickzelle, N., Huet, M., *et al.* 2017. Gene flow favours local adaptation under habitat choice in ciliate microcosms. *Nat. Ecol. Evol.* **1**: 1407–1410.

Jaeger, R.G. 1970. Potential extinction through competition between two species of terrestrial salamanders. *Evolution (N. Y).* **24**: 632–642.
Jandhyala, S.M., Talukdar, R., Subramanyam, C., Vuyyuru, H., Sasikala, M. & Reddy, D.N. 2015. Role of the normal gut microbiota. *World J. Gastroenterol.* **21**: 8836–8847.
Jasmin, J.-N., Dillon, M.M. & Zeyl, C. 2012. The yield of experimental yeast populations declines during selection. *Proc. Biol. Sci.* **279**: 4382–4388.
Jeltsch, F., Bonte, D., Pe'er, G., Reineking, B., Leimgruber, P., Balkenhol, N., *et al.* 2013. Integrating movement ecology with biodiversity research - exploring new avenues to address spatiotemporal biodiversity dynamics. *Mov. Ecol.* **1**: 1–13.
Johansson, J. 2007. Evolutionary responses to environmental changes: How does competition affect adaptation? *Evolution (N. Y).* **62**: 421–435.
Jones, A.G. 2008. A theoretical quantitative genetic study of negative ecological interactions and extinction times in changing environments. *BMC Evol. Biol.* **8**.
Kaimal, S.G. & Ramani, N. 2011. Feeding biology of Tetranychus ludeni zacher (Acari: Tetranychidae) on velvet bean. *Syst. Appl. Acarol.* **16**: 228–234.
Kant, M.R. 2004. Differential Timing of Spider Mite-Induced Direct and Indirect Defenses in Tomato Plants. *Plant Physiol.* **135**: 483–495.
Kant, M.R., Jonckheere, W., Knegt, B., Lemos, F., Liu, J., Schimmel, B.C.J., *et al.* 2015. Mechanisms and ecological consequences of plant defence induction and suppression in herbivore communities. *Ann. Bot.* **115**: 1015–1051.
Kant, M.R., Sabelis, M.W., Haring, M.A. & Schuurink, R.C. 2008. Intraspecific variation in a generalist herbivore accounts for differential induction and impact of host plant defences. *Proc. R. Soc. B* **275**: 443–452.
Kassambara, A. 2018. *ggpubr: "ggplot2" based publication ready plots. R package version 0.1.8*.
Katoh, K., Rozewicki, J. & Yamada, K.D. 2017. MAFFT online service: multiple sequence alignment, interactive sequence choice and visualization. *Brief. Bioinform.* 1–7.
Katoh, K. & Standley, D.M. 2013. MAFFT multiple sequence alignment software version 7: improvements in performance and usability. *Mol. Biol. Evol.* **30**: 772–780.
Kawecki, T.J. 2000. Adaptation to marginal habitats: contrasting influence of the dispersal rate on the fate of alleles with small and large effects. *Proc. R. Soc. B* **267**: 1315–1320.
Kawecki, T.J. 2008. Adaptation to marginal habitats. *Annu. Rev. Ecol. Evol. Syst.* **39**: 341–342.
Kawecki, T.J. 1995. Demography of source-sink populations evolution of ecological niches. *Evol. Ecol.* **9**: 38–44.
Kawecki, T.J. & Ebert, D. 2004. Conceptual issues in local adaptation. *Ecol. Lett.* **7**: 1225–1241. Wiley/Blackwell (10.1111).
Kawecki, T.J., Lenski, R.E., Ebert, D., Hollis, B., Olivieri, I. & Whitlock, M.C. 2012. Experimental evolution. *Trends Ecol. Evol.* **27**: 547–560.
Kembel, S.W., Cowan, P.D., Helmus, M.R., Cornwell, W.K., Morlon, H., Ackerly, D.D., *et al.* 2010. Picante: R tools for integrating phylogenies and ecology. *Bioinformatics* **26**: 1463–1464.
Kernaléguen, L., Arnould, J.P.Y., Guinet, C. & Cherel, Y. 2015. Determinants of individual foraging specialization in large marine vertebrates, the Antarctic and subantarctic fur seals. *J. Anim. Ecol.* **84**: 1081–1091. John Wiley & Sons, Ltd (10.1111).
Ketola, T., Mikonranta, L., Zhang, J., Saarinen, K., Örmälä, A.M., Friman, V.P., *et al.* 2013. Fluctuating temperature leads to evolution of thermal generalism and preadaptation to novel environments. *Evolution (N. Y).* **67**: 2936–2944.
Khalik, M.Z., Hendriks, K.P., Vermeulen, J.J. & Schilthuizen, M. 2019. Conchological and molecular analysis of the "non-scaly" Bornean Georissa with descriptions of three new species (Gastropoda, Neritimorpha, Hydrocenidae). *Zookeys* **840**: 35–86.
King, K.C. 2019. Defensive symbionts. *Curr. Biol.* **29**: R78–R80.
Kinnison, M.T., Hairston Jr., N.G. & Hendry, A.P. 2015. Cryptic eco-evolutionary dynamics. *Ann. N. Y. Acad. Sci.* **1360**: 120–144.
Kissling, W.D., Rahbek, C. & Böhning-Gaese, K. 2007. Food plant diversity as broad-scale determinant of avian frugivore richness. *Proc. R. Soc. B Biol. Sci.* **274**: 799–808.
Klopfer, P.H. & MacArthur, R.H. 1961. *On the causes of tropical species diversity: niche overlap*.
Knight, J. 2003. Negative results: null and void. *Nature* **422**: 554–555.

Knops, J.M.H., Tilman, D., Haddad, N.M., Naeem, S., Mitchell, C.E., Haarstad, J., *et al.* 1999. Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances and diversity. *Ecol. Lett.* **2**: 286–293. John Wiley & Sons, Ltd (10.1111).

Kohl, K.D. & Dearing, M.D. 2016. The woodrat gut microbiota as an experimental system for understanding microbial metabolism of dietary toxins. *Front. Microbiol.* **7**: 1165. Frontiers.

Kohl, K.D., Varner, J., Wilkening, J.L. & Dearing, M.D. 2018. Gut microbial communities of American pikas (*Ochotona princeps*): Evidence for phylosymbiosis and adaptations to novel diets. *J. Anim. Ecol.* **87**: 323–330. John Wiley & Sons, Ltd (10.1111).

Kohl, K.D., Weiss, R.B., Cox, J., Dale, C. & Dearing, M.D. 2014. Gut microbes of mammalian herbivores facilitate intake of plant toxins. *Ecol. Lett.* **17**: 1238–1246.

Kohn, A.J. 1978. Ecological shift and release in an isolated population: *Conus miliaris* at Easter Island. *Ecol. Monogr.* **48**: 323–336.

Kokko, H., Chaturvedi, A., Croll, D., Fischer, M.C., Guillaume, F., Karrenberg, S., *et al.* 2017. Can evolution supply what ecology demands? *Trends Ecol. Evol.* **32**: 187–197.

Kokko, H. & López-Sepulcre, A. 2007. The ecogenetic link between demography and evolution: Can we bridge the gap between theory and data? *Ecol. Lett.* **10**: 773–782.

Lankau, R.A. 2011. Rapid evolutionary change and the coexistence of species. *Annu. Rev. Ecol. Evol. Syst.* **42**: 335–54.

Law, R. & Daniel Morton, R. 1996. Permanence and the assembly of ecological communities. *Ecology* **77**: 762–775.

Lawrence, D., Fiegna, F., Behrends, V., Bundy, J.G., Phillimore, A.B., Bell, T., *et al.* 2012. Species interactions alter evolutionary responses to a novel environment. *PLoS Biol.* **10**: e1001330.

Le Rouzic, A. & Carlborg, Ö. 2007. Evolutionary potential of hidden genetic variation. *Trends Ecol. Evol.* **23**: 33–37.

Legrand, D., Cote, J., Fronhofer, E.A., Holt, R.D., Ronce, O., Schtickzelle, N., *et al.* 2017. Eco-evolutionary dynamics in fragmented landscapes. *Ecography (Cop.).* **40**: 9–25. Wiley/Blackwell (10.1111).

Lemon, J. 2006. Plotrix: a package in the red-light district of R. *R News* **6**: 8–12.

Lenormand, T. 2002. Gene flow and the limits to natural selection.

Lenth, R. 2019a. emmeans: estimated marginal means, aka least-squares means. R package version 1.3.2.

Lenth, R. 2019b. emmeans: estimated marginal means, aka least-squares means. R package version 1.3.5.1.

Leonardo, T.E. & Muiru, G.T. 2003. Facultative symbionts are associated with host plant specialization in pea aphid populations. *Proc. R. Soc. B* **270**: S209–S212.

Lewis, Z. & Lizé, A. 2015. Insect behaviour and the microbiome. *Curr. Opin. Insect Sci.* **9**: 86–90.

Li, J. & Margolies, D.C. 1993. Effects of mite age, mite density, and host quality on aerial dispersal behavior in the twospotted spider mite. *Entomol. Exp. Appl.* **68**: 79–86. John Wiley & Sons, Ltd (10.1111).

Liew, T.-S. 2019a. Bornean Terrestrial Molluscs.

Liew, T.-S. 2019b. Opisthostoma and Plectostoma (Family Diplommatinidae).

Liew, T.-S., Clements, R. & Schilthuizen, M. 2008. Sampling micromolluscs in tropical forests: one size does not fi t all. *Zoosymposia* **1**: 271–280.

Lindsey, H.A., Gallie, J., Taylor, S. & Kerr, B. 2013. Evolutionary rescue from extinction is contingent on a lower rate of environmental change. *Nature* **494**: 463–467. Nature Publishing Group.

Lister, B.C. & Garcia, A. 2018. Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proc. Natl. Acad. Sci. U. S. A.* **115**: E10397–E10406.

Lizé, A., Mckay, R. & Lewis, Z. 2014. Kin recognition in *Drosophila*: the importance of ecology and gut microbiota. *ISME J.* **8**: 469–477.

Longmuir, A., Shurin, J.B. & Clasen, J.L. 2007. Independent gradients of producer, consumer, and microbial diversity in lake plankton. *Ecology* **88**: 1663–1674.

Lozupone, C.A., Lladser, M.E., Knights, D., Stombaugh, J. & Knight, R. 2011. UniFrac: An effective distance metric for microbial community comparison. *ISME J.* **5**: 169–172. Nature Publishing Group.

Lucini, T., Faria, M.V., Rohde, C., Resende, J.T.V. & de Oliveira, J.R.F. 2015. Acylsugar and the role of trichomes in tomato genotypes resistance to Tetranychus urticae. *Arthropod. Plant. Interact.* **9**: 45–53.

Luck, G.W. 2007. A review of the relationships between human population density and biodiversity. *Biol.*

Rev. **82**: 607–645. John Wiley & Sons, Ltd (10.1111).
Łukasik, P., Guo, H., Van Asch, M., Ferrari, J. & Godfray, H.C.J. 2013. Protection against a fungal pathogen conferred by the aphid facultative endosymbionts Rickettsia and Spiroplasma is expressed in multiple host genotypes and species and is not influenced by co-infection with another symbiont. *J. Evol. Biol.* **26**: 2654–2661.
MacArthur, R.H. 1965. Patterns of Species Diversity. *Biol. Rev.* **40**: 510–533. John Wiley & Sons, Ltd (10.1111).
MacArthur, R.H. & Wilson, E.O. 1963. An equilibrium theory of insular zoogeography. *Evolution (N. Y).* **17**: 373–387. John Wiley & Sons, Ltd (10.1111).
MacArthur, R.H. & Wilson, E.O. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton.
Macke, E., Magalhães, S., Bach, F. & Olivieri, I. 2012. Sex-ratio adjustment in response to local mate competition is achieved through an alteration of egg size in a haplodiploid spider mite. *Proc. R. Soc. B* **279**: 4634–4642.
Macke, E., Magalhães, S., Khan, H.D.-T., Luciano, A., Frantz, A., Facon, B., *et al.* 2011. Sex allocation in haplodiploids is mediated by egg size: evidence in the spider mite *Tetranychus urticae* Koch. *Proc. R. Soc. B* **278**: 1054–1063.
Macke, E., Tasiemski, A., Massol, F., Callens, M. & Decaestecker, E. 2017. Life history and eco-evolutionary dynamics in light of the gut microbiota. *Oikos* **126**: 508–531.
Magalhães, S., Blanchet, E., Egas, M. & Olivieri, I. 2009. Are adaptation costs necessary to build up a local adaptation pattern? *BMC Evol. Biol.* **9**: 182.
Magalhães, S., Blanchet, E., Egas, M. & Olivieri, I. 2011. Environmental effects on the detection of adaptation. *J. Evol. Biol.* **24**: 2653–2662.
Magalhães, S., Cailleau, A., Blanchet, E. & Olivieri, I. 2014. Do mites evolving in alternating host plants adapt to host switch? *J. Evol. Biol.* **27**: 1956–1964.
Magalhães, S., Fayard, J., Janssen, A., Carbonell, D. & Olivieri, I. 2007. Adaptation in a spider mite population after long-term evolution on a single host plant. *J. Evol. Biol.* **20**: 2016–2027.
Magnusson, A., Skaug, H., Nielsen, A., Berg, C.W., Kristensen, K., Maechler, M., *et al.* 2018. Troubleshooting with glmmTMB.
Magurran, A.E. & McGill, B.J. 2011. *Biological diversity: Frontiers in measurement and assessment.* Oxford University Press.
Mallon, C.A., Le Roux, X., Van Doorn, G.S., Dini-Andreote, F., Poly, F. & Salles, J.F. 2018. The impact of failure: unsuccessful bacterial invasions steer the soil microbial community away from the invader's niche. *ISME J.* **12**: 728–741.
Martin, K. & Sommer, M. 2004. Relationships between land snail assemblage patterns and soil properties in temperate-humid forest ecosystems. *J. Biogeogr.* **31**: 531–545.
Martin, R.A. & Pfennig, D.W. 2009. Disruptive selection in natural populations: the roles of ecological specialization and resource competition. *Am. Nat.* **174**.
McGuigan, K. & Sgrò, C.M. 2009. Evolutionary consequences of cryptic genetic variation. *Trends Ecol. Evol.* **24**: 305–311.
Mcmurdie, P.J. & Holmes, S.P. 2013. phyloseq: An R Package for Reproducible Interactive Analysis and Graphics of Microbiome Census Data. *PLoS One* **8**: e61217.
Mendes, A., Fernandes, I.M., Penha, J. & Mateus, L. 2019. Intra and not interspecific competition drives intra-populational variation in resource use by a neotropical fish species. *Environ. Biol. Fishes* **102**: 1097–1105.
Meynard, C.N., Migeon, A. & Navajas, M. 2013. Uncertainties in predicting species distributions under climate change: a case study using Tetranychus evansi (Acari: Tetranychidae), a widespread agricultural pest. *PLoS One* **8**: 66445.
Miller, T.E., TerHorst, C.P. & Burns, J.H. 2009. The ghost of competition present. *Am. Nat.* **173**: 347–353.
Moosman, P.R., Thomas, H.H. & Veilleux, J.P. 2012. Diet of the widespread insectivorous bats *Eptesicus fuscus* and *Myotis lucifugus* relative to climate and richness of bat communities. *J. Mammal.* **93**: 491–496. Oxford University Press (OUP).
Moran, N.A. & Sloan, D.B. 2015. The hologenome concept: helpful or hollow? *PLoS Biol.* **13**: e1002311.
Muegge, B.D., Kuczynski, J., Knights, D., Clemente, J.C., González, A., Fontana, L., *et al.* 2011. Diet drives convergence in gut microbiome functions across mammalian phylogeny and within humans.

Science (80-.). **332**: 970–974.
Navajas, M. 1998. Host plant associations in the spider mite Tetranychus urticae (Acari: Tetranychidae): Insights from molecular phylogeography. *Exp. Appl. Acarol.* **22**: 201–214.
Navajas, M., De Moraes, G.J., Auger, P. & Migeon, A. 2013. Review of the invasion of Tetranychus evansi: biology, colonization pathways, potential expansion and prospects for biological control. *Exp. Appl. Acarol.* **59**: 43–65.
Navajas, M., Perrot-Minnot, M.J., Lagnel, J., Migeon, A., Bourse, T. & Cornuet, J.M. 2002. Genetic structure of a greenhouse population of the spider mite Tetranychus urticae: spatio-temporal analysis with microsatellite markers. *Insect Mol. Biol.* **11**: 157–165. John Wiley & Sons, Ltd (10.1111).
Neubert, M.G. & Caswell, H. 2000. Demography and dispersal: calculation and sensitivity analysis of invasion speed for structured populations. *Ecology* **81**: 1613–1628.
Nosil, P., Crespi, B.J. & Sandoval, C.P. 2003. Reproductive isolation driven by the combined effects of ecological adaptation and reinforcement. *Proc. R. Soc. B* **270**: 1911–1918.
Ochocki, B.M. & Miller, T.E.X. 2017. Rapid evolution of dispersal ability makes biological invasions faster and more variable. *Nat. Commun.* **8**: 14315.
Oke, O.C. & Chokor, J.U. 2009. The effect of land use on snail species richness and diversity in the tropical rainforest of south-western Nigeria. *African Sci.* **10**: 95–108.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., Minchin, P.R., *et al.* 2018. *Vegan: Community Ecology Package. R package version 2.5.3*.
Oku, K. 2014. Sexual selection and mating behavior in spider mites of the genus Tetranychus (Acari: Tetranychidae). *Appl. Entomol. Zool.* **49**: 1–9.
Oliver, K.M., Degnan, P.H., Burke, G.R. & Moran, N.A. 2010. Facultative symbionts in aphids and the horizontal transfer of ecologically important traits. *Annu. Rev. Entomol.* **55**: 247–266.
Oliver, K.M. & Higashi, C.H. 2019. Variations on a protective theme: *Hamiltonella* defensa infections in aphids variably impact parasitoid success. *Curr. Opin. Insect Sci.* **32**: 1–7.
Oliver, K.M., Moran, N.A. & Hunter, M.S. 2005. Variation in resistance to parasitism in aphids is due to symbionts not host genotype. *Proc. Natl. Acad. Sci.* **102**: 12795–12800.
Olson-Manning, C.F., Wagner, M.R. & Mitchell-Olds, T. 2012. Adaptive evolution. *Nat. Rev. Genet.* **13**: 867–877.
Osmond, M.M. & de Mazancourt, C. 2013. How competition affects evolutionary rescue. *Philos. Trans. R. Soc. London B, Biol. Sci.* **368**: 20120085. The Royal Society.
Parsons, P.A. 1990. The metabolic cost of multiple environmental stresses: Implications for climatic change and conservation. *Trends Ecol. Evol.* **5**: 315–317.
Pélabon, C., Hansen, T.F., Carter, A.J.R. & Houle, D. 2010. Evolution of variation and variability under fluctuating, stabilizing, and disruptive selection. *Evolution (N. Y).* **64**: 1912–1925.
Pelletier, F., Clutton-Brock, T., Pemberton, J., Tuljapurkar, S. & Coulson, T. 2007. The evolutionary demography of ecological change: Linking trait variation and population growth. *Science (80-.).* **315**: 1571–1574.
Pereira Silva, M.C., Cavalcante Franco Dias, A., Dirk van Elsas, J. & Salles, J.F. 2012. Spatial and temporal variation of archaeal, bacterial and fungal communities in agricultural soils. *PLoS One* **7**: e51554.
Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & R Core Team. 2015. nlme: linear and nonlinear mixed effects models. R package version 3.1-122.
Poisot, T., Bever, J.D., Nemri, A., Thrall, P.H. & Hochberg, M.E. 2011. A conceptual framework for the evolution of ecological specialisation. *Ecol. Lett.* **14**: 841–851.
Price, G.R. 1972. Fisher's "fundamental theorem" made clear. *Ann. Hum. Genet.* **36**: 129–140. John Wiley & Sons, Ltd (10.1111).
Price, M.N., Dehal, P.S. & Arkin, A.P. 2009a. Fasttree: Computing large minimum evolution trees with profiles instead of a distance matrix. *Mol. Biol. Evol.* **26**: 1641–1650.
Price, M.N., Dehal, P.S. & Arkin, A.P. 2009b. FastTree: computing large minimum evolution trees with profiles instead of a distance matrix. *Mol. Biol. Evol.* **26**: 1641–1650.
Price, M.N., Dehal, P.S. & Arkin, A.P. 2010. FastTree 2 - Approximately maximum-likelihood trees for large alignments. *PLoS One* **5**: e9490.
R Core Team. 2018. R: A language and environment for statistical computing. *R Found. Stat. Comput. Vienna, Austria.*

Rane, R. V, Ghodke, A.B., Hoffmann, A.A., Edwards, O.R., Walsh, T.K. & Oakeshott, J.G. 2019. Detoxifying enzyme complements and host use phenotypes in 160 insect species. *Curr. Opin. Insect Sci.* **31**: 1–8. Elsevier.

Raven, P.H. & Johnson, G.B. 2002. *Biology*. McGraw-Hill Education, Boston.

Raworth, D.A., Gillespie, D.R., Roy, M. & Thistlewood, H.M.A. 2001. Tetranychus urticae Koch, twospotted spider mite (Acari: Tetranychidae). In: *Biological Control Programmes in Canada, 1981-2000*, p. 259. CABI, Wallingford.

Renault, D., Laparie, M., Mccauley, S.J. & Bonte, D. 2017. Environmental adaptations, ecological filtering, and dispersal central to insect invasions. *Annu. Rev. Entomol.* **63**: 345–368.

Reznick, D.N., Bassar, R.D., Handelsman, C.A., Ghalambor, C.K., Arendt, J., Coulson, T., *et al.* 2019. Eco-evolutionary feedbacks predict the time course of rapid life history evolution. *Am. Nat.* 1–16.

Reznick, D.N. & Ghalambor, C.K. 2001. The population ecology of contemporary adaptations: what empirical studies reveal about the conditions that promote adaptive evolution. *Genetica* **112**: 183–198.

Rice, K.J. & Knapp, E.E. 2008. Effects of competition and life history stage on the expression of local adaptation in two native bunchgrasses. *Restor. Ecol.* **16**: 12–23. Wiley/Blackwell (10.1111).

Richardson, J.L., Urban, M.C., Bolnick, D.I. & Skelly, D.K. 2014. Microgeographic adaptation and the spatial scale of evolution. *Trends Ecol. Evol.*, doi: 10.1016/j.tree.2014.01.002.

Ricker, W.E. 1954. Stock and Recruitment. *J. Fish. Res. Board Canada* **11**: 559–623.

Robinson, D.G. 1999. Alien invasions: the effects of the global economy on non-marine gastropod introductions into the United States. *Malacologia* **41**: 413–438.

Rodrigues, L.R., Duncan, A.B., Clemente, S.H., Moya-Laraño, J. & Magalhães, S. 2016. Integrating Competition for Food, Hosts, or Mates via Experimental Evolution. *Trends Ecol. Evol.* **31**: 158–170. Elsevier Ltd.

Romero, J. & Navarrete, P. 2006. 16S rDNA-based analysis of dominant bacterial populations associated with early life stages of Coho salmon (*Oncorhynchus kisutch*). *Microb. Ecol.* **51**: 442–430.

Rudman, S.M., Greenblum, S., Hughes, R.C., Rajpurohit, S., Kiratli, O., Lowder, D.B., *et al.* 2019. Microbiome composition shapes rapid genomic adaptation of Drosophila melanogaster. *Proc. Natl. Acad. Sci. U. S. A.* **116**: 20025–20032. National Academy of Sciences.

Saccheri, I. & Hanski, I. 2006. Natural selection and population dynamics. *Trends Ecol. Evol.* **21**: 341–347.

Sánchez-Bayo, F. & Wyckhuys, K.A.G. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biol. Conserv.* **232**: 8–27.

Sánchez-Piñero, F. & Polis, G.A. 2000. Bottom-up dynamics of allochthonous input: direct and indirect effects of seabirds on islands. *Ecology* **81**: 3117–3132.

Sanchez, G. 2013. PLS Path Modeling with R (383rd ed.).

Sanchez, G., Trinchera, L. & Russolillo, G. 2017. plspm: tools for partial least squares path modeling (pls-pm). Comprehensive R Archive Network (CRAN).

Santo Domingo, J.W., Kaufman, M.G., Klug, M.J., Holben, W.E., Harris, D. & Tiedje, J.M. 1998. Influence of diet on the structure and function of the bacterial hindgut community of crickets. *Mol. Ecol.* **7**: 761–767.

Santos-Matos, G., Wybouw, N., Martins, N.E., Zélé, F., Riga, M., Leitão, A.B., *et al.* 2017. Tetranychus urticae mites do not mount an induced immune response against bacteria. *Proc. R. Soc. B* **284**: 1–8.

Sarmento, R.A., Lemos, F., Bleeker, P.M., Schuurink, R.C., Pallini, A., Oliveira, M.G.A., *et al.* 2011a. A herbivore that manipulates plant defence. *Ecol. Lett.* **14**: 229–236.

Sarmento, R.A., Lemos, F., Dias, C.R., Kikuchi, W.T., Rodrigues, J.C.P., Pallini, A., *et al.* 2011b. A herbivorous mite down-regulates plant defence and produces web to exclude competitors. *PLoS One* **6**: 8–15.

Sato, Y., Alba, J.M. & Sabelis, M.W. 2014. Testing for reproductive interference in the population dynamics of two congeneric species of herbivorous mites. *Heredity (Edinb).* **113**: 495–502. Nature Publishing Group.

Scarborough, C.L., Ferrari, J. & Godfray, H.C.J. 2005. Aphid protected from pathogen by endosymbiont. *Science (80-.).* **310**: 1781.

Schilthuizen, M. 2011. Community ecology of tropical forest snails: 30 years after Solem. *Contrib. to Zool.* **80**: 1–15.

Schilthuizen, M., Chai, H.-N., Kimsin, T.E. & Vermeulen, J.J. 2003. Abundance and diversity of land-snails (Mollusca: Gastropoda) on limestone hills in Borneo. *Raffles Bull. Zool.* **51**: 35–42.

Schilthuizen, M., Liew, T.-S., Bin Elahan, B. & Lackman-Ancrenaz, I. 2005. Effects of karst forest degradation on pulmonate and prosobranch land snail communities in Sabah, Malaysian Borneo. *Conserv. Biol.* **19**: 949–954.

Schilthuizen, M. & Njunjić, I. 2019. cave lists Kinabatangan. *10.13140/RG.2.2.26761.90726.*

Schlichting, C.D. 2008. Hidden reaction norms, cryptic genetic variation, and evolvability. *Ann. N. Y. Acad. Sci.* **1133**: 187–203.

Schluter, D. 1994. Experimental evidence that competition promotes divergence in adaptive radiation. *Science (80-.).* **266**: 798–801.

Schoener, T.W. 2011. The newest synthesis: Understanding the interplay of evolutionary and ecological dynamics. *Science (80-.).* **331**: 426–429.

Seedorf, H., Griffin, N.W., Ridaura, V.K., Reyes, A., Cheng, J., Rey, F.E., *et al.* 2014. Bacteria from diverse habitats colonize and compete in the mouse gut. *Cell* **159**: 253–266.

Seehausen, O. 2007. Evolution and ecological theory: chance, historical contingency and ecological determinism jointly determine the rate of adaptive radiation. *Heredity (Edinb).* **99**: 361–363.

Shapira, M. 2016. Gut Microbiotas and Host Evolution: Scaling Up Symbiosis. *Trends Ecol. Evol.* **31**: 539–549.

Shin, S.C., Kim, S.-H., You, H., Kim, B., Kim, A.C., Lee, K.-A., *et al.* 2011. *Drosophila* microbiome modulates host developmental and metabolic homeostasis via insulin signaling. *Science (80-.).* **334**: 670–674.

Siemann, E., Tilman, D., Haarstad, J. & Ritchie, M. 1998. Experimental tests of the dependence of arthropod diversity on plant diversity. *Am. Nat.* **152**: 738–750. Whittaker Logan.

Siepielski, A.M., Nemirov, A., Cattivera, M. & Nickerson, A. 2016. Experimental evidence for an eco-evolutionary coupling between local adaptation and intraspecific competition. *Am. Nat.* **187**: 447–456.

Silvertown, J. 2004. The ghost of competition past in the phylogeny of island endemic plants. *J. Ecol.* **92**: 168–173. Wiley/Blackwell (10.1111).

Smallegange, I.M. & Coulson, T. 2013. Towards a general, population-level understanding of eco-evolutionary change. *Trends Ecol. Evol.* **28**.

Sommer, F. & Bäckhed, F. 2013. The gut microbiota-Masters of host development and physiology. *Nat. Rev. Microbiol.* **11**: 227–238.

Sörenson, E., Bertos-Fortis, M., Farnelid, H., Kremp, A., Krüger, K., Lindehoff, E., *et al.* 2019. Consistency in microbiomes in cultures of *Alexandrium* species isolated from brackish and marine waters. *Environ. Microbiol. Rep.* **11**: 425–433. John Wiley & Sons, Ltd (10.1111).

Spencer, H. 1864. *The Principles of Biology*. Williams and Norgate, London.

Spor, A., Koren, O. & Ley, R. 2011. Unravelling the effects of the environment and host genotype on the gut microbiome. *Nat. Rev. Microbiol.* **9**: 279–290.

Stadler, J., Trefflich, A., Klotz, S. & Brandl, R. 2000. Exotic plant species invade diversity hot spots: the alien flora of northwestern Kenya. *Ecography (Cop.).* **23**: 169–176.

Staudacher, H., Schimmel, B.C.J., Lamers, M.M., Wybouw, N., Groot, A.T. & Kant, M.R. 2017. Independent effects of a herbivore's bacterial symbionts on its performance and induced plant defences. *Int. J. Mol. Sci.* **18**: 1–26.

Stecher, B. & Hardt, W.D. 2008. The role of microbiota in infectious disease. *Trends Microbiol.* **16**: 107–114.

Stewart, R.I.A., Dossena, M., Bohan, D.A., Jeppesen, E., Kordas, R.L., Ledger, M.E., *et al.* 2013. Mesocosm Experiments as a Tool for Ecological Climate-Change Research. *Adv. Ecol. Res.* **48**: 71–181. Academic Press.

Stilling, R.M., Bordenstein, S.R., Dinan, T.G. & Cryan, J.F. 2014. Friends with social benefits: host-microbe interactions as a driver of brain evolution and development? *Front. Cell. Infect. Microbiol.* **4**: 147. Frontiers.

Strauss, S.Y. 2014. Ecological and evolutionary responses in complex communities: Implications for invasions and eco-evolutionary feedbacks. *Oikos* **123**: 257–266.

Stuart, Y.E., Campbell, T.S., Hohenlohe, P.A., Reynolds, R.G., Revell, L.J. & Losos, J.B. 2014. Rapid evolution of a native species following invasion by a congener. *Science (80-.).* **346**: 463–466.

Svanbäck, R. & Bolnick, D.I. 2007. Intraspecific competition drives increased resource use diversity within

a natural population. *Proc. R. Soc. B Biol. Sci.* **274**: 839–844.
Svanbäck, R., Rydberg, C., Leonardsson, K. & Englund, G. 2011. Diet specialization in a fluctuating population of *Saduria entomon*: a consequence of resource or forager densities? *Oikos* **120**: 848–854.
Szűcs, M., Vahsen, M.L., Melbourne, B.A., Hoover, C., Weiss-Lehman, C. & Hufbauer, R.A. 2017. Rapid adaptive evolution in novel environments acts as an architect of population range expansion. *Proc. Natl. Acad. Sci.* **114**: 13501–13506.
Takeuchi, Y., Chaffron, S., Salcher, M.M., Shimizu-Inatsugi, R., Kobayashi, M.J., Diway, B., *et al.* 2015. Bacterial diversity and composition in the fluid of pitcher plants of the genus *Nepenthes*. *Syst. Appl. Microbiol.* **38**: 330–339.
Tanner, J.T. 1975. The stability and the intrinsic growth rates of prey and predator populations. *Ecology* **56**: 855–867.
Theis, K.R., Venkataraman, A., Dycus, J.A., Koonter, K.D., Schmitt-Matzen, E.N., Wagner, A.P., *et al.* 2013. Symbiotic bacteria appear to mediate hyena social odors. *Proc. Natl. Acad. Sci.* **110**: 19832–19837.
Therneau, T.M. 2015a. A Package for Survival Analysis in R.
Therneau, T.M. 2015b. coxme: mixed effects cox models. R package version 2.2-5.
Therry, L., Zawal, A., Bonte, D. & Stoks, R. 2014. What factors shape female phenotypes of a poleward-moving damselfly at the edge of its range? *Biol. J. Linn. Soc.* **112**: 556–568.
Thomas, J.A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D., Asher, J., *et al.* 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science (80-.).* **303**: 1879–1881.
Thuiller, W., Lavorel, S., Araújo, M.B., Sykes, M.T., Prentice, I.C. & Mooney, H.A. 2005. Climate change threats to plant diversity in Europe. *Proc. Natl. Acad. Sci. U. S. A.* **7**: 8245–8250.
Tien, N.S.H., Sabelis, M.W. & Egas, M. 2010. The maintenance of genetic variation for oviposition rate in two-spotted spider mites: inferences from artificial selection. *Evolution (N. Y).* **64**: 2547–2557.
Tilman, D. & Pacala, S. 1993. The maintenance of species richness in plant communities. In: *Species diversity in ecological communities* (R. E. Ricklefs & D. Schluter, eds), pp. 13–25. University of Chicago Press, Chicago.
Trapletti, A. & Hornik, K. 2018. tseries: time series analysis and computational finance (R package version 0.10-45).
Turcotte, M.M., Corrin, M.S.C. & Johnson, M.T.J. 2012. Adaptive evolution in ecological communities. *PLoS Biol.* **10**: e1001332.
Turcotte, M.M., Reznick, D.N. & Hare, J.D. 2011a. Experimental assessment of the impact of rapid evolution on population dynamics. *Evol. Ecol. Res.* **13**: 113–131.
Turcotte, M.M., Reznick, D.N. & Hare, J.D. 2013. Experimental Test of an Eco-Evolutionary Dynamic Feedback Loop between Evolution and Population Density in the Green Peach Aphid. *Am. Nat.* **181**: S46–S57.
Turcotte, M.M., Reznick, D.N. & Hare, J.D. 2011b. The impact of rapid evolution on population dynamics in the wild: experimental test of eco-evolutionary dynamics. *Ecol. Lett.* **14**: 1084–1092.
Uesugi, R. & Osakabe, M.H. 2007. Isolation and characterization of microsatellite loci in the two-spotted spider mite, Tetranychus urticae (Acari: Tetranychidae). *Mol. Ecol. Notes* **7**: 290–292. John Wiley & Sons, Ltd (10.1111).
Urban, M.C., De Meester, L., Vellend, M., Stoks, R. & Vanoverbeke, J. 2012. A crucial step toward realism: Responses to climate change from an evolving metacommunity perspective. *Evol. Appl.* **5**: 154–167. Wiley/Blackwell (10.1111).
Vala, F., Breeuwer, J.A.J. & Sabelis, M.W. 2003. Sorting out the effects of Wolbachia, genotype and inbreeding on life-history traits of a spider mite. *Exp. Appl. Acarol.* **29**: 253–264.
Valero-Mora, P.M., Valero-Mora & M., P. 2010. ggplot2: Elegant Graphics for Data Analysis.
Van Leeuwen, T. & Dermauw, W. 2016. The molecular evolution of xenobiotic metabolism and resistance in Chelicerate mites. *Annu. Rev. Entomol.* **61**: 475–498.
Van Leeuwen, T., Stillatus, V. & Tirry, L. 2004. Genetic analysis and cross-resistance spectrum of a laboratory-selected chlorfenapyr resistant strain of two-spotted spider mite (Acari: Tetranychidae). *Exp. Appl. Acarol.* **32**: 249–261.
Van Leeuwen, T., Vanholme, B., Van Pottelberge, S., Van Nieuwenhuyse, P., Nauen, R., Tirry, L., *et al.* 2008. Mitochondrial heteroplasmy and the evolution of insecticide resistance: non-Mendelian

inheritance in action. *Proc. Natl. Acad. Sci.* **105**: 5980–5985.
van Opstal, E.J. & Bordenstein, S.R. 2015. Rethinking heritability of the microbiome. *Science (80-.).* **349**: 1172–1173.
Van Petegem, K., Moerman, F., Dahirel, M., Fronhofer, E.A., Vandegehuchte, M.L., Van Leeuwen, T., *et al.* 2018. Kin competition accelerates experimental range expansion in an arthropod herbivore. *Ecol. Lett.* **21**: 225–234.
Van Valen, L. 1973. A new evolutionary law. *Evol. Theory* **1**: 1–30.
Van Valen, L. 1965. Morphological variation and width of ecological niche. *Am. Nat.* **99**: 377–390.
van Veelen, H.P.J., Salles, J.F. & Tieleman, B.I. 2018. Microbiome assembly of avian eggshells and their potential as transgenerational carriers of maternal microbiota. *ISME J.* **12**: 1375–1388.
Vannette, R.L. & Fukami, T. 2014. Historical contingency in species interactions: towards niche-based predictions. *Ecol. Lett.* **17**: 115–124.
Vellend, M. 2010. Conceptual Synthesis in Community Ecology. *Q. Rev. Biol.* **85**: 183–206.
Venail, P.A., MacLean, R.C., Bouvier, T., Brockhurst, M.A., Hochberg, M.E. & Mouquet, N. 2008. Diversity and productivity peak at intermediate dispersal rate in evolving metacommunities. *Nature* **452**: 210–214.
Veneti, Z.L., Reuter, M., Montenegro, H., Hornett, E.A., Charlat, S. & Hurst, G.D. 2005. Interactions between inherited bacteria and their hosts: The *Wolbachia* paradigm. In: *The influence of cooperative bacteria on animal host biology* (M.-J. McFall-Ngai, B. Henderson, & E.-G. Ruby, eds), pp. 119–142. Cambridge University Press, New York.
Vermeulen, J.J., Liew, T.S. & Schilthuizen, M. 2015. Additions to the knowledge of the land snails of sabah (Malaysia, Borneo), including 48 new species. *Zookeys* **2015**: 1–139. PENSOFT PUBL, 12 PROF GEORGI ZLATARSKI ST, SOFIA, 1700, BULGARIA.
Villéger, S., Blanchet, S., Beauchard, O., Oberdorff, T. & Brosse, S. 2011. Homogenization patterns of the world's freshwater fish faunas. *PNAS* **108**: 18003–18008.
Violle, C., Nemergut, D.R., Pu, Z. & Jiang, L. 2011. Phylogenetic limiting similarity and competitive exclusion. *Ecol. Lett.* **14**: 782–787.
Vizzini, S., Signa, G. & Mazzola, A. 2016. Guano-derived nutrient subsidies drive food web structure in coastal ponds. *PLoS One* **11**: e0151018.
Vorburger, C. & Perlman, S.J. 2018. The role of defensive symbionts in host-parasite coevolution. *Biol. Rev. Camb. Philos. Soc.* **93**: 1747–1764. John Wiley & Sons, Ltd (10.1111).
Wagner, G.P. & Altenberg, L. 1996. Perspective: complex adaptations and the evolution of evolvability. *Evolution (N. Y).* **50**: 967–976.
Walde, S.J. 1995. Internal dynamics and metapopulations: experimental tests with predator-prey systems. *Popul. Dyn.* 173–193. Academic Press.
Walsh, M.R. 2013. The evolutionary consequences of indirect effects. *Trends Ecol. Evol.* **28**: 23–29. Elsevier Ltd.
Wang, I.J. & Bradburd, G.S. 2014. Isolation by environment. *Mol. Ecol.* **23**: 5649–5662.
Watkins, B. & Simkiss, K. 1990. Interactions between soil bacteria and the molluscan alimentary tract. *J. Molluscan Stud.* **56**: 267–274.
Webster, N.B., Van Dooren, T.J.M. & Schilthuizen, M. 2012. Phylogenetic reconstruction and shell evolution of the Diplommatinidae (Gastropoda: Caenogastropoda). *Mol. Phylogenet. Evol.* **63**: 625–638.
Weiss-Lehman, C., Hufbauer, R.A. & Melbourne, B.A. 2017. Rapid trait evolution drives increased speed and variance in experimental range expansions. *Nat. Commun.* **8**: 14303.
Weiss-Lehman, C., Tittes, S., Kane, N.C., Hufbauer, R.A. & Melbourne, B.A. 2019. Stochastic processes drive rapid genomic divergence during experimental range expansions. *Proceedings. Biol. Sci.* **286**: 20190231.
Weldon, S.R., Strand, M.R. & Oliver, K.M. 2013. Phage loss and the breakdown of a defensive symbiosis in aphids. *Proc. R. Soc. B* **280**: 1–7.
Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon* **21**: 213–251. John Wiley & Sons, Ltd.
Wickham, H. 2016. *ggplot2: elegant graphics for data analysis*. Springer-Verlag New York.
Winter, M., Schweiger, O., Klotz, S., Nentwig, W., Andriopoulos, P., Arianoutsou, M., *et al.* 2009. Plant extinctions and introductions lead to phylogenetic and taxonomic homogenization of the

European flora. *PNAS* **106**: 21721–21725.
Wybouw, N., Van Leeuwen, T. & Dermauw, W. 2018. A massive incorporation of microbial genes into the genome of Tetranychus urticae , a polyphagous arthropod herbivore. *Insect Mol. Biol.* **27**: 333–351. John Wiley & Sons, Ltd (10.1111).
Wybouw, N., Zhurov, V., Martel, C., Bruinsma, K.A., Hendrickx, F., Grbić, V., *et al.* 2015. Adaptation of a polyphagous herbivore to a novel host plant extensively shapes the transcriptome of herbivore and host. *Mol. Ecol.* **24**: 4647–4663.
Xie, R.R., Sun, J.T., Xue, X.F. & Hong, X.Y. 2016. Cytoplasmic incompatibility and fitness benefits in the two-spotted spider mite Tetranychus urticae (red form) doubly infected with Wolbachia and Cardinium. *Syst. Appl. Acarol.* **21**: 1161–1173.
Yates, M.C. & Fraser, D.J. 2014. Does source population size affect performance in new environments? *Evol. Appl.* **7**: 871–882.
Yoshida, T., Jones, L.E., Ellner, S.P., Fussmann, G.F. & Hairston Jr., N.G. 2003. Rapid evolution drives ecological dynamics in a predator–prey system. *Nature* **424**: 303–306. Nature Publishing Group.
Young, K.A., Snoeks, J. & Seehausen, O. 2009. Morphological diversity and the roles of contingency, chance and determinism in African cichlid radiations. *PLoS One* **4**: e4740.
Youngblut, N.D., Reischer, G.H., Walters, W., Schuster, N., Walzer, C., Stalder, G., *et al.* 2019. Host diet and evolutionary history explain different aspects of gut microbiome diversity among vertebrate clades. *Nat. Commun.* **10**: 2200.
Zélé, F., Santos-Matos, G., Figueiredo, A.R.T., Eira, C., Pinto, C., Laurentino, T.G., *et al.* 2019. Spider mites escape bacterial infection by avoiding contaminated food. *Oecologia* **189**: 111–122.
Zélé, F., Santos, I., Olivieri, I., Weill, M., Duron, O. & Magalhães, S. 2018a. Endosymbiont diversity and prevalence in herbivorous spider mite populations in South-Western Europe. *FEMS Microbiol. Ecol.* **94**: fiy015.
Zélé, F., Santos, J.L., Godinho, D.P. & Magalhães, S. 2018b. Wolbachia both aids and hampers the performance of spider mites on different host plants. *FEMS Microbiol. Ecol.* **94**: 187.
Zhang, P.-J., Zheng, S.-J., van Loon, J.J.A., Boland, W., David, A., Mumm, R., *et al.* 2009. Whiteflies interfere with indirect plant defense against spider mites in Lima bean. *Proc. Natl. Acad. Sci.* **106**: 21202–21207.
Zhang, Z.Q. 2003. *Mites of greenhouses: identification, biology and control*. CABI Publishing, Wallingford.
Zhao, X.F., Buckling, A., Zhang, Q.G. & Hesse, E. 2018. Specific adaptation to strong competitors can offset the negative effects of population size reductions. *Proc. R. Soc. B Biol. Sci.* **285**: 20180007.
Zhu, Y.-X., Song, Y.-L., Zhang, Y.-K., Hoffmann, A.A., Zhou, J.-C., Sun, J.-T., *et al.* 2018. Incidence of facultative bacterial endosymbionts in spider mites associated with local environments and host plants. *Appl. Environ. Microbiol.* **84**: e02546-17.
Zilber-Rosenberg, I. & Rosenberg, E. 2008. Role of microorganisms in the evolution of animals and plants: the hologenome theory of evolution. *FEMS Microbiol. Rev.* **32**: 723–735.
Zuk, M. & Travisano, M. 2018. Models on the Runway: How Do We Make Replicas of the World?*. *Am. Nat.* **192**: 1–9.

Curriculum vitae

Education

2014 – 2019

PhD student	Joint PhD in Evolutionary Biology
Institution	Ghent University (UGent, Department of Biology, Terrestrial Ecology – TEREC) University of Groningen (RUG, GELIFES, Theoretical Research in Evolutionary Life Sciences – TRÊS)

2009 – 2014

MSc student	Master in Biology, major in Ecology and Evolution (summa cum laude), Ghent University
Dissertation	Evolution of ecological specialisation under competition (supervision: Prof. Dr. Dries Bonte)
Erasmus	Boreal Biota and Ecology Program (University of Helsinki, UH)
BSc student	Bachelor in Biology (cum laude), Ghent University
Dissertation	Groepseffecten bij *Tetranychus urticae* ('group effects within *Tetranychus urticae'*) (supervision: Prof. Dr. Dries Bonte)
Internships	**CRC, KMDA,** Antwerp: Helping with ongoing research, such as sexing of birds and paternity analysis, helping with finalizing genetic diet analysis by the investigation of manure samples (tutor: Vanya Prévot) **Planckendael**, Mechelen: Behavioural observations of bonobos in (tutor: Evelien De Groot) **Bird Ecology Unit (UH),** Helsinki: Census of small mammals (tutor: Diego Pavon Jordan) **TEREC (UGent**): Helping in adaptation experiment study (tutor: Adriana Alzate Vallejo), monitoring populations and assessing life history traits (tutor: Annelies De Roissart), ArcGIS work for insect research on chalk grasslands (tutor: Toos van Noordwijk)

Teaching Experience

Daily supervisor

2014 – 2019	**MSc dissertation** (RUG and UGent): supervision of five MSc students **Community Ecology Research course** (RUG): supervision of 14 BSc students **Field Biological Research course** (UGent): supervision of 11 BSc students **BSc internship** (RUG): supervision of a BSc student from the Indian Institute of Technology

Teaching assistant

2014 – 2016	**Ecology** (UGent) **Population Ecology** (UGent)

Funding and Awards

2017	Leopold III grant for field work in Sabah, Malaysian Borneo
2014	Special Research Fund (BOF, UGent) for PhD funding
	Ubbo Emmius sandwich program (RUG) for PhD funding
	Price Pierre Verkerk for best MSc thesis in Biology (UGent)

Publications

Bisschop, K., Mortier, F., Etienne, R. S., Bonte, D. (2019) Transient local adaptation and source-sink dynamics in experimental populations experiencing spatially heterogeneous environments, *Proc. R. Soc. B,* 286: 20190738

Hendriks, K. P., **Bisschop, K.**, Kavanagh, J. C., Kortenbosch, H. H., Larue, A. E. A., Richter Mendoza F. J., Schilthuizen, M., Etienne, R. S. (2019) Fieldwork to sample microsnails for diet and microbiome studies along the Kinabatangan river, Sabah, Malaysian Borneo, *The Malacologist*, 72: 33-38

Alzate, A.*, **Bisschop, K.***, Etienne, R. S., Bonte, D. (2017) Interspecific competition counteracts negative effects of dispersal on adaptation of an arthropod herbivore to a new host, *Journal of Evolutionary Biology*, 30(11), 1966-1977

Bisschop, K., Mortier, F., Bonte, D., Etienne, R. (under review) Performance in a novel environment subject to ghost competition, *PeerJ*

Bisschop, K.*, Kortenbosch, H. H.*, J. B. van Eldijk, T. J. B., Mallon, C. A., Salles, J. F., Bonte, D., Etienne, R. S. (under review), Microbiome heritability and its role in adaptation of hosts to novel resources, *PNAS*

Hendriks, K. P.*, **Bisschop, K.***, Kortenbosch, H. H., Kavanagh, J. C., Larue, A. E. A., Phung, C.-C., Bonte, D., Duijm, E. J., Salles, J. F., Pigot, A. L., Richter Mendoza, F. J., Schilthuizen, M., Speksnijder, A. G. C. L., Etienne, R. S. (under review) Microbiome and environment explain the absence of correlations between consumers and their diet in Bornean microsnails, *Ecology*

Goldenberg, J., D'Alba, L., **Bisschop, K.**, Vanthournout, B., Shawkey, M. D. (under review) Keep it cool: Ventral color evolution in response to substrate heat capacity in ectotherms, *PNAS*

van Eldijk, T., **Bisschop, K.**, Etienne, R. S. (submitted) Uniting community ecology and evolutionary rescue: Community-Wide Rescue, *Frontiers in Ecology and Evolution*

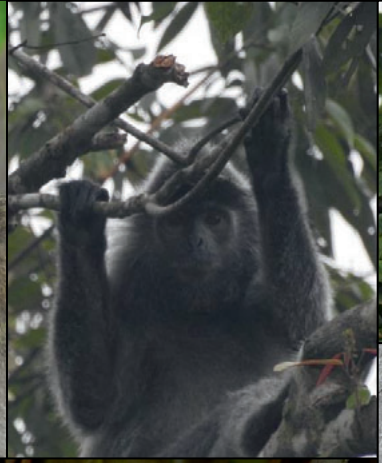
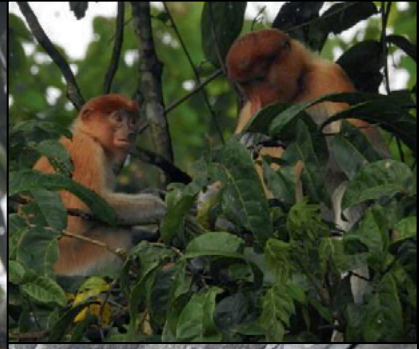
* Joint first author

Conferences

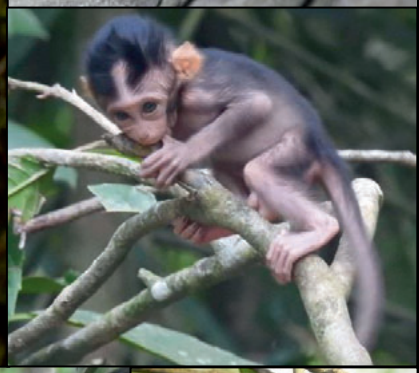
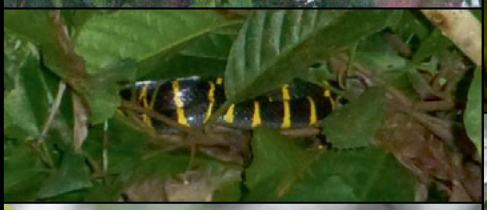
2018	**NAEM,** Lunteren, The Netherlands (session convener)
2017	**NAEM**, Lunteren, The Netherlands (oral presentation: Unravelling processes behind local adaptation: experimental evolution)
	ESEB, Groningen, The Netherlands (oral presentation: Competition and spatial heterogeneity shape eco-evolutionary dynamics of ecological specialisation)
2014	**BES-SFE**, Lille, France (oral presentation: Evolution of ecological specialization under competition)

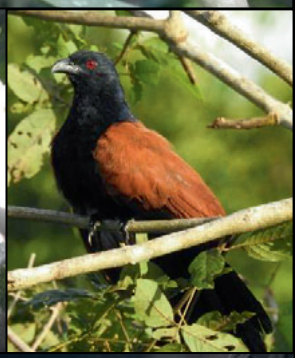
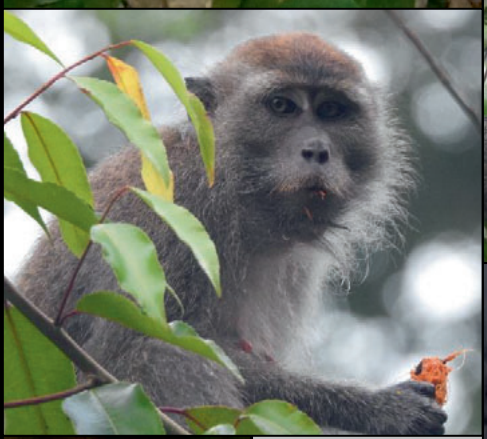
Additional training

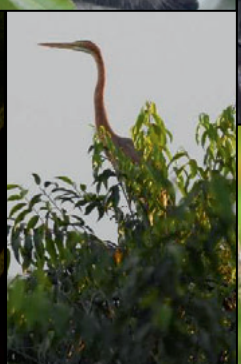
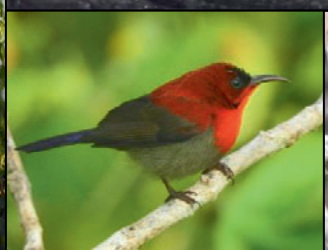
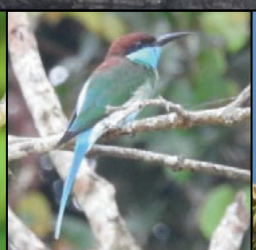
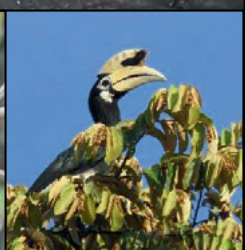
2013 – 2019	Genetic Modified Organisms (RUG)
	Principles of Ecological Genomics (SENSE, Wageningen)
	Advanced Biostatistics (UGent, C003345)
	Survival Analysis in R (UGent)
	Advanced Academic English: Conference Skills – Academic Posters and English Proficiency for Presentations (UGent, Doctoral Schools)

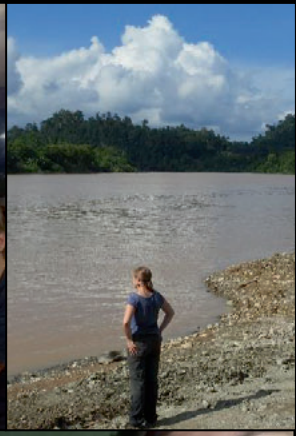












Acknowledgements

First of all, I would like to thank my supervisors. Dries, you started supervising me for both my BSc and MSc projects and you gave me the chance to pursue my research through a PhD. I am very grateful you introduced me to the fields of ecology and evolution, culminating into the world of experimental evolution (and the spider mites with whom I have a bit of a love-hate relationship). I am especially thankful for always supporting me and believing in me. You were there to answer all my questions and to give me extra hands for making the work more feasible. Rampal, thank you for your enthusiasm (both in science and music) and your infinite support. You gave me the chance to further develop my skills by giving me the opportunity to study microbiomes and performing field work in Borneo. Thanks a lot for assisting me and being there when things were not going as they should. Joana, I really want to thank you for your assistance with the microbiome research. You were very helpful, and I am happy for all the feedback you provided. Frederik, although you are officially no longer my supervisor (due to some problems with the DNA quality of my populations), I would still like to thank you for giving me the chance to learn more about genetics, for letting me use the laboratory in the Royal Belgian Institute of Natural Sciences and for continuing to support me despite the drawbacks.

Before continuing I would like to thank Prof. Dr. Ellen Decaestecker, Prof. Dr. Matthew Shawkey, Prof. Dr. Ir. Thomas Van Leeuwen, and Prof. Dr. Bregje Wertheim for their willingness to be part of my assessment committee and for their time to read my entire thesis. Besides, I also want to thank Dr. Martijn Egas, Dr. Ir. Marjon de Vos, and Dr. Nicky Wybouw for their enthusiasm to be part of the jury.

Dries and Rampal, both of you have wonderful research groups and I am extremely lucky to be part of them. I will first start with everyone I would like to thank from my time in Ghent University. Katrien and Annelies, I first met both of you as my supervisors for my bachelor project. I remember that I talked about life as a PhD student and that Katrien answered me that when I really want to do a PhD, I should just try to go for it and that is what I did. After being a student, we became colleagues and I am so happy that I met you both! Jasmijn, during our PhD we grew closer together and it was wonderful to develop such a good friendship. Walking together in the citadel park, drinking tea in the kitchen at the 11th, waiting way too long for food at De Vos, laughing if we did something silly, drinking cocktails at your bachelorette, and dancing together at your wedding. I will never forget those moments, thanks a lot for being there for me! Irene, although I was most of the time in Groningen when you were my housemate, I still really enjoyed living with you. The effort you made to get up earlier to have breakfast with me, asking me in the evening what my dinner plans were and if you could help me carrying stuff; but most of all, just being there for listening to everything I had to tell, for assisting me when I needed it and for giving me advice, thank you! Adriana, I was a bit in doubt in which part I had to mention you as you were my daily supervisor for my MSc project, but afterwards a colleague in both Ghent and Groningen. I would like to thank you for assisting me during my thesis, but also for letting me be part of your defence as one your paranymphs. Frederik, you were my first MSc student and I am really grateful for that, because without you I would not have been able to deal with the enormous workload during the experiment. Afterwards,

you became a colleague and a good friend, that is always there when I need it, thank you! Stefano, my 'little' brother, I know deep inside, you do not think I am that terrible. Thank you for being there and for always being very honest. Viki and Angelica, thank you for being there for administration and technical assistance! Although that will not be how I will remember you, both of you are always in for drinks or pizza/noodle/wok and for helping to keep an amazing work atmosphere, thank you so much! Pieter, the first time I met you was to help during my MSc project with the amazing spider mites. You were one of my rescuers when the workload was not bearable anymore, thank you so much, also for all your help afterwards. Jiao, I will not forget your arrival at the Ledeganck, you directly offered us presents which showed how generous and thoughtful you are. Together with Pei you also organised some amazing dinners and let us celebrate Chinese New Year, I would like to thank both of you for that! Steven, you are actually really nice despite the fact that you are from Dendermonde ;-) it was also really good to have you around for the nematode adventure. Bram, I admire your energy and talent to combine so many events. Besides everything, you were still there for going for a picnic in the Citadel Park or a drink at the corner, I always liked our conversations and hope to see you soon! Daan, the first time I got in touch with you was with a very formal email for a BSc project about bats (I know you laughed a lot with it, but you were more than allowed, I would have done the same). Thank you for joining the night projects at the terrestrial internships, you always stayed positive and helpful regardless of whether it was day or night. Femke, if you have some waffles left over, you can always come and bring them. Thank you for always being there! Laurence, I wish you a lot of luck with your flute and I hope that I can hear you once during a concert. Alejandro, it is awesome that I could always count on you for going for a drink or having fun at a party! Bethelehem, when I left to Groningen you made an amazing meal for me, I was really flattered by that. I hope you are doing great and I will see you again! Further, I would also like to thank Hans, Luc, Martijn, Lionel, Ruben, Dries, Thomas, Jens, Cátia, Jan, Joost, Diederik, Liesbeth, Matti, Tim, Johan, Lynda, Tanja, Jeroen, Steven, Helena, Marwa, and Alexandre. And also special thanks to Jelle for going together through the work of our MSc projects and making it a great time. Lunch times and parties would not have been the same without the amazing people from limnology and EON! Thank you Dirk, Liliana, Jorunn, Els, Svana, Thijs, Gijs, Lore, Bram, Yoeri, and Mike! Federico, it was great that I could be a part of your research in South-Africa, thank you! Although my time at the RBINS did not lead to nice results, I would still like to thank Carl, Katrien and Marie for being there and helping me with the lab work and analyses.

But, as mentioned above, my life in Groningen would not have been as great as it was now without a lot of people. Pedro, thanks for being my paranymph or should I call you my 'maid of honour' ;-). You are an amazing drummer and a wonderful friend. Giovanni, you were there (almost) from the start of my PhD and my life in Groningen would not have been the same without you. Kasper, joining you for the fieldtrip to Borneo was incredible and I also really enjoyed our collaborations afterwards, I hope we can keep in touch! Cyrus, you are one of the first people I met in Groningen and I am so happy we are able to work together on the chemostat project. Pancho, it was sad you had to move back to Chile, but I am happy we are still in touch, you are a great friend! Raphaël, it is wonderful to have you in the group, I will miss your enthusiasm and never-ending energy. Liang, you were a fixed value in the group and I wish you all the best for the future! Leonel, although I miss

you sitting behind me, I hope you are having an amazing time in Scotland! Looking forward to use SecSSE! Richèl, you were there when I did not know a lot of people yet and I am very grateful for that, thanks for organising Giacomondays and Keivrijdagen! Theo, my roommate without actually sharing a room! It is great you can manage to come now and then back to Groningen and I hope to see you soon again! Shu, you are such a wonderful positive friend and, although it was sometimes a bit too spicy, your food is incredible! Thanks for organising horror movie nights! Josh, the soon-to-be SecSSE and herpetology expert, I wish you all the best! Lucas, although you just arrived in our group, it seems like I know you already for a long time and I hope we can keep in touch. Tianjian, enjoy your time in Groningen! Hylke, thank you so much for being such a great MSc student and friend. I know you do not want to deal with spider mites ever again, but I would not have been able to do it without you. Timo, it is incredible how many new ideas someone can have even in one day, you are a great scientist and musician. Anaïs and James, I really enjoyed my time with both of you, our fieldtrip to Borneo will forever be in my mind and I wish you both an amazing future. Sebastian, always relaxed and providing us with chocolates or other sweets. Your cordylid catching skills in South-Africa were great and also jamming would not have been the same without you, thank you so much! Moniek, it is admirable how good you are in distinguishing the bacteria from the chemostat, thank you for helping us! Paul, I really enjoyed your company in the office, the birding trips you organised and the drinks after work. Josselin, I will not forget the confusion you caused in our group before your arrival. Some people were expecting a girl which did not seem to be the case. Thank you for the nice chats in De Minnaar and I hope to see you again soon! Marina, the amazing time outside hours would not have been the same without you, thank you so much for organising movie nights, dinners and drinks. I will also never forget your reaction when you found out about Maya! Always welcome to come to Ghent for babysitting while we provide board and lodging ;-). Pratik, I was pleasantly surprised by your knowledge at the pub quiz in Café De Toeter. It is great to have you around at parties, you are really a fixed value in our group! Xiaoyan, thank you for making the movie during our music recording and also for always being there for a nice chat! Andrea, the starter of our international movie nights and initially a member of our jamming groups. It was always great to have you around and I hope to see you again soon! Annelies, I am very happy that part of TRES and Conseco were fused in COCON when I started in Groningen, in this way I was able to meet you! Dinners and sport (the few times I went bouldering and swimming) were great with you! Nadia, always so enthusiast and willing to help, it is wonderful to have you around, I hope we can soon go back to the lake with the unicorn and boat or go to Noorderplantsoen for a picnic or a drink! Yvonne, my almost flatmate, always there for a chat, drink or party. I am looking forward to seeing you on your wedding with the toddlers throwing flowers (although I had the feeling that Florian did not seem very enthusiast about that idea…). Beatriz, I really enjoyed the tapas and game we played for your birthday, our time together at the lake, and the Life congress last year! Koosje and Lisa, a big hug for both of you, thank you for your company and I hope we can keep in touch. Ingeborg, thank you for always answering whichever question related to administration, but also for your patience and pleasant chats. Joke, thank you for organising the TRES seminars and your help with dataverse! Corine, thank you for all the help especially at the start of my PhD. Jacob and Jan, without both of you I would not have been able to perform my experiments here in Groningen. Thank you so much for arranging

the climate rooms and providing help when it was needed. Furthermore, I would like to thank Alex, Luis, Thijs, Hanno, Annabel, Femke, Akashi, Bouwe, Fons, Anne-Marie, Boris, Albertas, Christoph, Stefano, Inès, Aparajitha, Jakob, Jan, Lauren, Jana, Marta, Miguel, Matteo, Stefany, Marina, Elodie, Tiphaine, Megan, Gerrit, David, Daniel, Helen, Omer, Luis, Samyuktha, Kevin, Rik and Bjorn.

The research would not have been possible without some collaborators I would like to thank: Sara Magalhães, Menno Schilthuizen, Elza Duim, Chee-Chean Phung, and Arjen Speksnijder.

I would also like to thank some of my friends from high school. Last years I have not seen you very often, but I really appreciate the effort you are doing in arranging a date to see me, thank you so much Margot, Katrien, Karl-Jan, Tom, Michiel, Romy, Vincent, Michiel and Glenn. When I was still in Belgium, I used to play theatre with JETIE and Tijl & Nele, some of the friendship I made there are life-long. Thank you for all the support you are giving me and being there for me: Ineke, Amanda, Thijs, Lotte, Matthias, Ina, Frank, Michiel, Chloë and Jonathan. If I talk about hobbies and amazing groups of people that partly shaped my life, I have to mention VKSJ. Although I was not always there, I love our brunches, our talks, and our parties. Thank you Noortje, Fedra, Astrid, Lissa, Silke, Evelien and Justine! Lise and Lore, I am so happy that I know you already for such a long time and that we somehow manage to keep in touch (I know a bit more times per year would be better). During my studies in biology at Ghent University I met some amazing people that I must mention here. Maaike, Eline, Thomas and Katrien, I will not forget the support you all gave me during my PhD and also our time together in Suriname (and for Maaike also in Iceland). It was such a great experience and it strengthened our friendship even more. Maxime, Jana, Annelore, and Sanne thank you for all the time we spend together! Lisanne, I am always surprised that we have been only such a short time together at university, because it feels like you were always there! Good luck in Canada! Stijn, thank you for being my diary! Emily, Hannah, Myrtle, Charlotte, Bartelijn, Rieneke, Sari, Yasmine, you girls are amazing and I hope we can keep in touch!

All of this would not have been possible without my loving family and especially my parents, Johan and Hilde, and my sister, Leen. Papa, mama, Leen, thank you all so much for constructing the light-boxes to improve the quality of the spider mite pictures, for helping with organising the set-up and the datasets, for trying to automate the spider mite counts, for helping me in the lab on days as Christmas and New Year (because spider mites do not care about holidays), for being there for me and giving me advise at any time of the day and for your infinite support. This booklet would not have been here without you! Thank you all so much! Jonathan, I am so happy you chose to do a PhD in Ghent and that you came to visit me in Groningen. Our friendship got in another dimension and I cannot imagine how my life would be without you. Our life will change a lot in the coming months with little Maya, but I am so much looking forward to it. Thank you for always being there for me!

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